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Washington, D. C. 20015

December 1975

Final Report

Prepared For:

Principal Investigations Management Office
David Amsbury, Technical Monitor
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

NAS9-13297

EREP Investigation No. 495

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ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

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PREFACE

Our proposal submitted to NASA in April of 1971 noted that:

The petroleum industry in this country must find some means of arresting the deteriorating cost/success ratio of domestic petroleum exploration. We believed that petroleum exploration could be improved by new financially efficient exploration procedures, and that orbital imagery may constitute one of these.

The results of our ERTS experiment (Collins et al., 1974) and of this study indicate that this intuitive postulate is true, even for relatively well explored areas such as the Anadarko Basin, and it is particularly true for the less explored areas of this country and relatively unexplored areas abroad.

This need for new, more cost-effective techniques is particularly important at present. Our proposal also noted that:

> "Numerous governmental commissions and agencies as well as oil and gas industry associations have recently spotlighted the fact that the nation is now in (and faces in the forseeable future) an energy shortage of serious dimensions. Salient facts and considerations are:
>
> > Gas distribution companies have long lists of customers waiting for new connections;
> >
> > Many industrial or utility plants face problems of converting from gas to coal or oil with all the attendant pollution and ecological problems;
> >
> > Importation of crude oil and liquid natural gas is on and will be on the upswing -- the nation is dependent on foreign supply;
> >
> > Prices for oil and gas at all levels of distribution are rising (both foreign and domestic) thus bringing more fuel to the furnace of inflation;
> >
> > Domestic inland exploratory spending and drilling activity are at a record low level since World War II;
> >
> > Domestic oil and gas reserves are declining despite substantial increases in demand; and,

> The nuclear power industry has not expanded at the rates predicted for earlier forecasts because of public opposition."

Except for the fifth condition, the present situation is essentially as noted in 1971. The need for increased effectiveness in domestic petroleum exploration was urgent at the time we submitted the proposal and has become even more so consequent to the OPEC actions of the past three years.

A thoughtful appraisal of this situation can only lead to the conclusion that every aspect of new technology applicable to petroleum exploration must be exhaustively tested in order to:

> Optimize technical efforts using customary tools by rapidly focusing exploration attention on the most promising areas;
>
> Reduce the time needed for exploration;
>
> Maximize the cost savings through both of these.

In the months since the launchings of ERTS-1 (now Landsat) and Skylab, data from earth satellites have earned a place among more conventional exploration methods. The substantial sums of money, time and manpower already invested in satellite data by explorationists, research organizations, schools and universities, government agencies, planners, and casual users attest to their high expectations of such data. Indeed, many have already shown significant results. It only remains to draw upon these few years of experience and to optimize orbital earth resources programs in order to fulfill many of these expectations. Then orbital remote sensing can truly become an effective standard exploration tool.

ACKNOWLEDGEMENTS

We are grateful to NASA for including us in the Skylab Principal Investigator Program and particularly to the very helpful team who made the program work: Mr. Martin Miller, Dr. David Amsbury, Mr. Von Frierson and Dr. Victor Mazade. And we cannot forget the astronauts of the Skylab program, the people of the NASA aircraft program and all the people involved in processing and distributing the data. We thank the many people who have shared their knowledge and experience in the Anadarko Basin with us, including Drs. Mankin, Johnson, and Fay, and John Roberts of the Oklahoma Geological Survey, Drs. Myers, Wickham, and Kitts of the School of Geology at the University of Oklahoma, William Jackson of Eason Oil Company, and Dr. R. E. (Tim) Dennison of Dallas, Texas. We are grateful to the many people who have offered helpful criticism and suggestions during the progress of the experiment. Special thanks go to Louise Skinner who typed, retyped, and reproduced this and our other reports, and to Monty Hott of Eason Oil Company for his drafting.

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I. INTRODUCTION

INTRODUCTION

Objectives

The objectives of this study are to:

1. Evaluate the ability of Skylab imagery to contribute to an understanding of the geology of the Anadarko Basin -- particularly to contribute to our understanding of the tectonic history of that basin as it relates to hypotheses for oil and gas exploration;

2. Assess the realistic costs of using these data;

3. Assess the value of this imagery as one of the specialized analytical techniques available to small and middle-sized oil exploration companies;

4. Determine the types and amounts of information of value to petroleum exploration that can be extracted from Skylab data;

5. Determine the best data products, methods, and techniques to use to extract this information;

6. Determine the costs of acquiring and using these data for petroleum exploration relative to the costs of obtaining similar information using conventional means; and,

7. Compare the results from Skylab with those from our ERTS study of the same area.

In particular we wanted to determine the ability of Skylab data to delineate major structural features and to test Skylab as a reconnaissance exploration tool in a geologically well known area in order to assess its usefulness in an unknown area. We did not set out to find oil in the Anadarko Basin, but rather have used it as a geologically well known area in which to test a new exploration tool.

Background

Skylab Orbital Missions:

Pete Conrad, Joe Kerwin, Paul Weitz: The first skylab crew confirmed man can live, work and repair a crippled ship in space. Their mission, Skylab-2, lasted 26 days, from May 26, 1973 to June 19.

Al Bean, Owen Garriott, Jack Lousma: The Skylab-3 mission

lasted more than 59 days, from July 28, 1973 to September 25. In addition to many earth resources passes, this crew accomplished amazing repairs, one EVA lasting 6½ hours. Arabella the spider stole the publicity.

Gerald Carr, Ed Gibson, Bill Pogue: An endurance record of 84 days in space was started on November 16, 1973 by the crew of Skylab-4. This crew also accomplished a 6½ hour EVA, studied Comet Kohoutek and put the Skylab into mothballs on February 8, 1974.

The unmanned Saturn Workshop was launched as Skylab-1 on May 14, 1973. It is still in orbit.

The Earth Resources studies were carried out at an altitude of about 450 km (280 mi). The orbit is inclined at 50° to the earth's poles, thereby covering the earth between 50° north and 50° south latitude. The period is about 93 minutes and each orbital track is repeated every 5 days.

Anadarko Basin Test Site:

This Skylab study (NASA project S495) evaluates imagery of the Anadarko Basin (test site 333) and studies its applicability to hydrocarbon exploration. It was funded entirely by Eason Oil Company of Oklahoma City.

The Anadarko Basin lies in western Oklahoma and the Panhandle of Texas. It is an area that has been extensively explored for petroleum for more than 50 years.

We relied primarily on standard image interpretation techniques, and applied these techniques to black-and-white, color, and color composite products in transparency and positive print forms. Scales varied from 1:1,000,000 through 1:100,000. In addition to this work, we evaluated several enhancement techniques and digital data manipulation techniques.

Throughout the study we integrated the Skylab data with field work, published reports, Landsat (ERTS) imagery, and multiband-multisensor data collected by aircraft. The latter data were provided by NASA and were collected in support of our ERTS and Skylab studies and for several other studies.

Remarks

Earth Resources Programs to Date:

The greatest problems for geological studies from Skylab originated from the limited nature of the program and the

irregularly scheduled EREP passes along with the multi-discipline experimental program. Inspite of five successful passes over our study site, we do not have a complete set of imagery either from a single pass or in combination from several passes. This situation arises because of: 1) orbital constraints (a small part of the area could not have been covered except by an orbit shift); 2) persistent and recurring clouds and snow; 3) pre-emption because of mechanical problems (the ideal day for our site was rescheduled for a practice run of the EVA to emplace the portable sun shield); and 4) pre-emption by other studies dependent on transient phenomena such as solar flares.

These constraints on Skylab give Landsat an advantage in that its program and orbital parameters almost guarantee 100% repetitive coverage with fairly consistent quality of almost the entire earth. Skylab gave us a chance to view the earth from a new vantage point by means of new applications of several sensing devices. However, the imagery in essence simply added to a library of airborne imagery of variable kinds, scales, quality and locations.

Skylab-like data are desirable. A program designed to provide full time to earth resources observations, with repetitive coverage and data of consistent quality is a must.

It must also be emphasized here that Skylab had the distinct advantage of being manned. Were it not for the repairs and changes made by the flight crews, there would have been no EREP passes.

This Study:

Landsat is the current NASA designation for the original ERTS satellites. In this report "Landsat" will be used when referring to the actual ERTS-1 satellite or data produced by it. However, when reference is made to a study that was done under the early ERTS name, the acronym ERTS will be used to avoid confusion because all references to the satellite were made by that name when the work was done. Many papers published on early work have ERTS as a key word in the title.

It should also be noted that in many sections of this report data and information on Landsat will be interwoven with the results of our Skylab study. This is not intended to give Skylab results in terms of Landsat studies, but is a convenience for presenting Skylab results and at the same time comparing them to Landsat.

Summary of Results

Skylab data (S190A and B photos in particular) are exceedingly valuable for obtaining a rapid geologic assessment of large areas and for relatively detailed study of specific areas of interest. Skylab data provide a host of information on regional lithologic and structural relationships, and quickly draw attention to anomalous features and areas that are of greatest interest to petroleum exploration. Such features include major fracture trends and several types of anomalies.

The data enable one to confirm, refine or modify existing interpretations, and supply a certain amount of new information, particularly about regional relationships. Perhaps most important of all, Skylab gives one a new perspective for looking at the earth and raises many new questions that serve as a basis for additional inquiry. The data have caused us to begin a reappraisal of the conventional model of the Anadarko Basin.

Skylab, like any other data source, does not answer all questions but rather is a starting point for regional explorations and a means of improving on interpretations made from Landsat data. In order for information derived from Skylab data to be useful in petroleum exploration, it must be integrated effectively with a wide variety of other types of data and included within the structure of a rational exploration strategy.

At the very least, the advantages of Skylab data may be obtained at little or no extra cost to a conventional exploration program. At the other extreme, benefits may range up to 40% cost savings in an exploration program. Advantages gained by using Skylab data in decision-making and time savings are among the many additional intangible and incalculable advantages.

Landsat MSS images are superior to S192 images because of better resolution and lower noise content. Lithologic interpretations may be made accurately from MSS and S192. The MSS permits more rapid delineation than S192, but S192 has the advantage of many narrow bands. Bands 2 through 5 of S192 are best for rapid delineation of major rock units. Bands 6 through 12 show significantly more detail, particularly topographic or geomorphic detail. All bands have a high noise content.

S190A and S190B photos are superior to S192 data for most geologic purposes. The normal color and the red band of S190A are the most useful of the six bands. Color prints

made from S190B at 1:250,000 or larger are the best among all the imaging sensors for geologic studies. Large scale S190B photos are superior to high altitude airphoto mosaics in situations where very high resolution is not critical.

Linears interpreted from Skylab are similar in azimuths to Landsat linears. They relate well to joints and subsurface faults but are not diagnostic of these features. Some known surface faults were mapped and several previously unknown faults were inferred from Skylab, something that was not done from Landsat. Field studies show that many long linears are associated with disturbed zones in surface rock exposures. Anomalies are fewer but less ambiguous than similar anomalies from Landsat. Fifteen known Landsat anomalies were confirmed by Skylab. Completely closed subcircular anomalies and tonal anomalies show the highest correlation to known hydrocarbon features. Lithologic interpretations from Skylab are generally accurate but do not always match exactly published interpretations. Most important, Skylab images show areas where remapping may be desirable. We recommend remapping of the Pliocene Ogallala, certain Pleistocene sand units and part of the Permian Hennessey-Wellington contact in southern Oklahoma.

Discussions with other investigators lead us to the decision not to use the digital tapes of S193 data. The results of computer manipulation of S192 data were disappointing, particularly when compared to the photographic products. The spectral resolution of the S192 scanner could lead to sophisticated differentiation of surface composition units. However, the high noise content of the tapes and the level of effort required to use them together with the nature of our study lead us to conclude that computer manipulation of S192 data is not time- or cost- effective in the Anadarko Basin for hydrocarbon exploration.

II. ANADARKO BASIN TEST SITE

ANADARKO BASIN TEST SITE

General Description

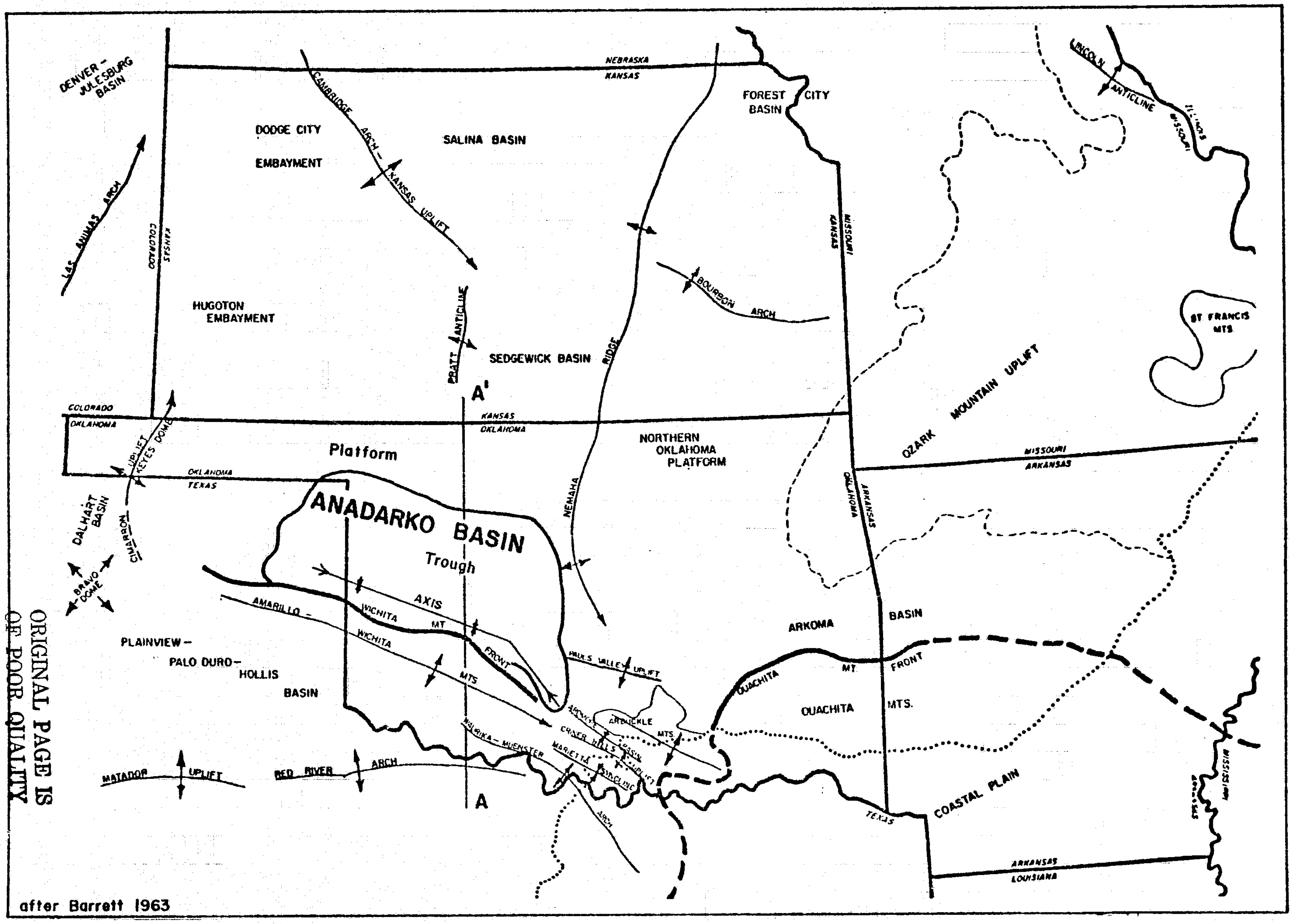
The Anadarko Basin occupies about 76,800 square km in western Oklahoma and the Panhandle of Texas (Map 1) and is bounded approximately by 34°45' and 37° north latitude and 97° 30' and 101° 30' west longitude. The basin was chosen as a test site because there is a great deal of published information available on the geology of the area and many structures act as traps for hydrocarbons. The Anadarko Basin is also similar to several other large epicontinental sedimentary basins. In addition, the area was the site of Eason Oil Company's ERTS experiment (Collins *et al*., 1974).

The rocks in the Anadarko Basin have undergone several periods of deformation which culminated with faulting, folding, and rapid deposition during Pennsylvanian and early Permian time. Essentially flat lying Permian clastic and evaporite rocks overlie and mask most of the underlying structural features. Some areas include collapse features produced by solution of evaporites. This complex history makes the Anadarko an exacting test of the usefulness of Skylab imagery for petroleum exploration.

Climate of the area ranges from moist sub-humid in the north and eastern parts of the area to semi-arid in the western part of the area. Rainfall ranges from one meter per year in the east to less than 40 centimeters per year in the far west. Consequently, native vegetation ranges from scrub oak in the east to short prairie grass and sage in the west.

Altitude of the surface steadily rises from 300 meters in the east to 1,500 meters in the west. Topography in the east is characterized by gently rolling hills with local relief of approximately 60 meters. In the west the topography is characterized by flat undissected uplands and mesas and deep canyons with local relief on the order of 350 meters.

The entire area is extensively farmed and ranched and most land holdings are divided along township and range survey lines. This imposes a north-south and east-west oriented cultural lineation over much of the area. Constancy of the pattern makes it easy to separate man-made linears from natural linears. Cultural features not parallel to this grid can be eliminated by interpretation or by reference to USGS 1:250,000 scale topographic maps.



Map 1. Regional setting of Anadarko Basin. Cross section A-A' is shown in figure 1.

Extensive agricultural usage results in tonal patterns produced by cultivated vegetation and cultivated soils imposed upon and replacing native vegetation and undisturbed soils. Much of what one interprets is, in the final analysis, sensor response to vegetation and soils. Thus at some seasons of the year the cultivated vegetation tends to mask natural boundaries and at other times of the year it serves to accurately mark these boundaries.

Geology

The following summary of the geology of the Anadarko Basin was derived from several sources, mainly Wheeler (1955), Huffman (1959), Eddlemen (1961), Cunningham (1961), MacLachlin (1964), Ham *et al.*, (1964), Petzel (1974), and Collins *et al.*, (1974).

Location:

The Anadarko Basin trends west-northwest from near Oklahoma City into Texas County, Oklahoma (Map 1). The basin is bounded by the Nemaha ridge on the east, the Amarillo-Wichita-Criner Hills mountain chain on the south, the Cimarron uplift at the west end, and along the north by the Hugoton-Dodge City embayment and the Central Kansas uplift. The axis of the basin lies about 35 km north of the Amarillo-Wichita uplift.

For the purposes of this study the Anadarko Basin is defined by the -3000 feet (-920 meters) structural contour (datum is sea level) on the top of the Mississippian (MacLachlan, 1964). It can be divided into a platform and a trough. The trough is defined on the south by the frontal structural zone of the Amarillo-Wichita uplift. The -6000 feet contour (-1830 meters) on the Mississippian or the hingeline of Atokan deposition define the western and northern bounds. The Atokan hingeline and the -6000 feet contour approximately coincide. The hingeline is placed where thickening of sedimentary units increases from 10 ft/mile on the platform to about 50 ft/mile into the trough (Rascoe, 1962). The west-northwest trending axis of the basin lies near the south edge of the trough, giving the basin a strongly asymmetrical character (Figure 1).

Stratigraphy:

Layered basement rocks above the Precambrian substrate (1,100 and 1,350 million years old) total 7600 meters thick

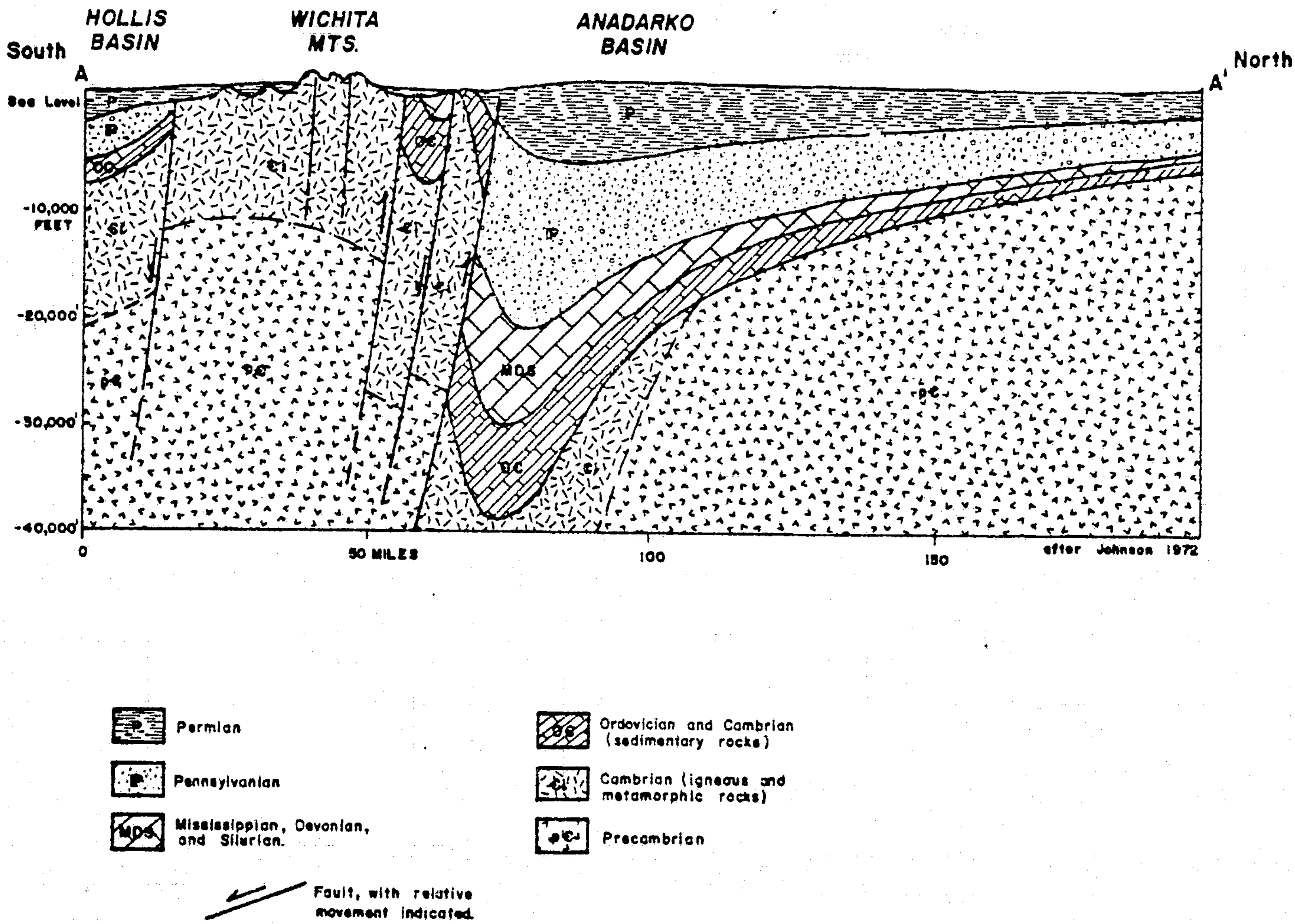


Figure 1. Cross section through the Wichita Mountains and Anadarko Basin showing asymmetry of the basin and the complex frontal structure of the Wichitas. Line of section shown on maps 1, 2.

near the axis of the basin (Ham *et al.*, 1964). They consist of late Precambrian and early Cambrian metasedimentary rocks, early or middle Cambrian basalt and gabbro and late Cambrian granite and rhyolite.

Unconformably overlying the basement rocks is a series of sedimentary rocks representing every system from Cambrian through Quaternary. These rocks are as much as 11,500 meters thick near the axis. Paleozoic rocks thin northward onto the platform, being thickest in the present trough. Younger rocks reflect epeirogenic movements and distant orogenies and thus usually do not show thickening in the trough area.

Late Cambrian through Mississippian rocks are predominately limestone and dolomite. The first major hiatus in the record occurs in Devonian time at the end of Hunton deposition. The Hunton is unconformably overlain by Devonian-Mississippian Woodford shale. Pennsylvanian through lower Permian rocks are predominately clastic rocks in the basin with limestones and dolomites interbedded in the shelf area to the north. The remainder of Permian rocks are clastic with significant thicknesses of interbedded evaporites.

Mesozoic rocks are limited to a few small exposures mostly on the periphery of the basin and are not of major concern to this study.

The Tertiary is represented by the Pliocene Ogallala formation composed of continental rocks that crop out over most of the area west and north of central Roger Mills County, Oklahoma.

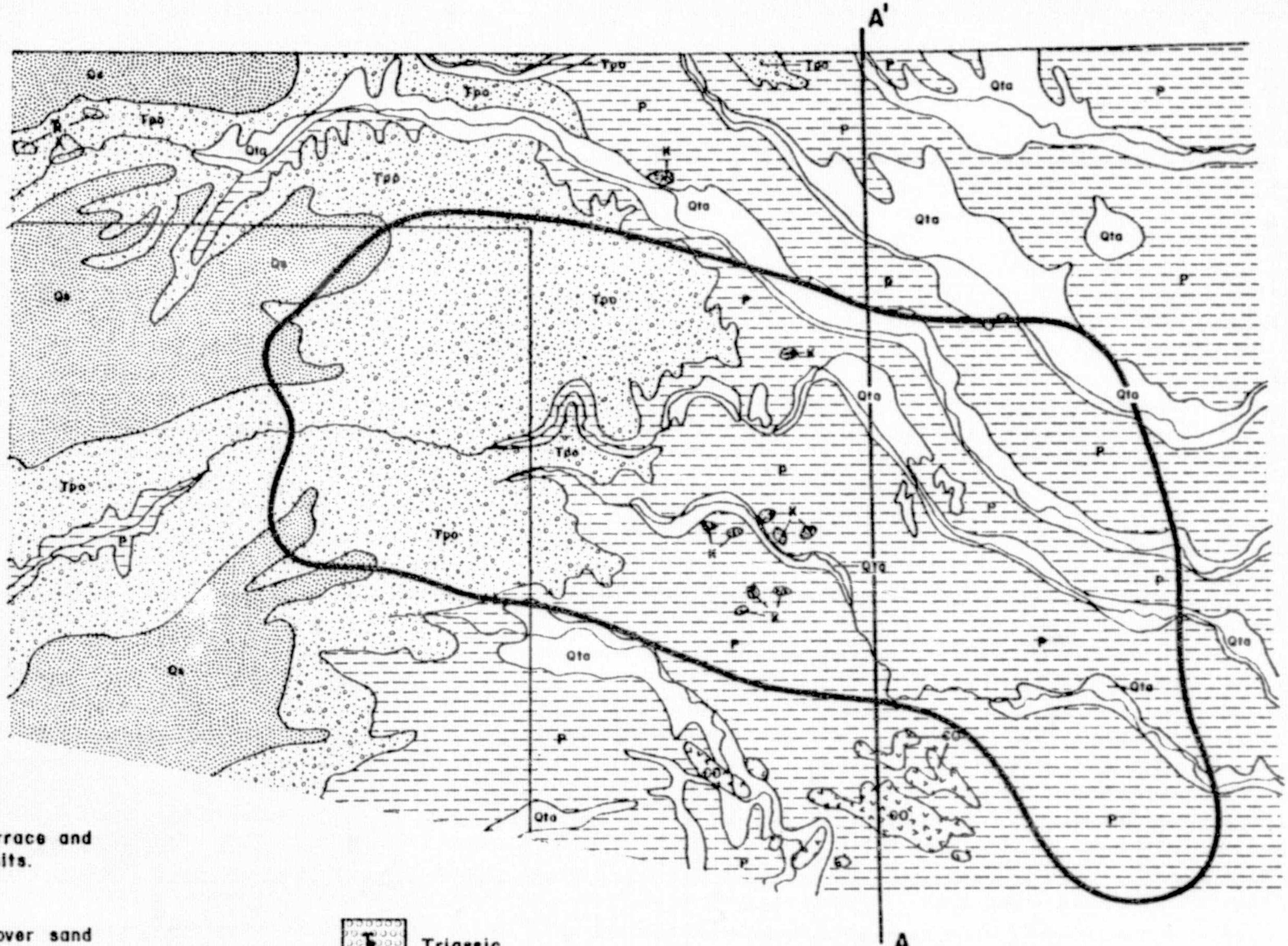
Large areas on uplands and along major streams are covered by Quaternary wind-blown and stream-laid deposits.

Surface Rocks:

Cambrian and Ordovician rocks are exposed in the Wichita Mountains to the south of the Anadarko Basin, and isolated outcrops of Mesozoic rocks occur at several places (Map 2).

Permian, Pliocene and Quaternary deposits are the most widespread surface units. Permian rocks are dominately shallow-marine, deltaic and alluvial deposits of red sandstone, shale and evaporite rocks. Gypsum and dolomite outcrops form conspicuous scarps. Thick salt units are widespread in the subsurface, affecting the surface by solution collapse and by local increases in salinity of surface and groundwater.

Map 2: Generalized Geologic Map Of The Anadarko Basin.



Qta	Quaternary: terrace and alluvial deposits.
Qs	Quaternary: cover sand on uplands
Tpo	Tertiary: pliocene, Ogallala formation.
K	Cretaceous
Ꞧ	Triassic
P	Permian: redbeds, undifferentiated.
€O	Cambrian and Ordovician outcrops of Wichita Mtns.

0 10 20 30 MI

0 10 20 30 40 50 Km.

Scale: 1:2,000,000

(After Branson & Johnson, 1972)

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Pliocene Ogallala sediments are poorly consolidated, poorly sorted gravel, sand and clay with several layers of volcanic ash and bentonitic clay. Caliche occurs irregularly in the upper part of the exposed Ogallala.

Many upland areas in Texas and all major drainages are occupied by Pleistocene eolian and fluvial deposits. Older deposits include sand, gravel and volcanic ash, whereas the younger are terrace deposits of gravel, sand, silt and clay with numerous channel deposits. Younger Pleistocene and recent dunes exist along several large streams and on some uplands. In addition, there are playa deposits in many small blowout depressions, particularly in the Pleistocene cover near Amarillo.

Tectonics and Geologic History:

In late Cambrian time, seas spread into the mid-continent from the Ouachita trough to the south. In the southern Oklahoma embayment Precambrian clastic rocks were re-worked and deposited as the Reagan Sandstone.

The embayment axis trended west-northwest from central Oklahoma to the Sierra Grande highland to the west. This axis was probably close to the present axis of the Amarillo-Wichita-Criner Hills uplift (Ham et al., 1964). Several areas of high relief affected sedimentation. Among these were Sierra Grande, "Llanoria" to the south and the central Kansas arch on the northeast. By the time of deposition of the Cambrian-Ordovician Arbuckle Group the crust in the vicinity of the present Anadarko Basin had developed into a broad sag. Minor structural adjustments caused thinning and local unconformities in units near the margin of the basin. This pattern of deposition continued essentially uninterrupted into mid-Devonian time. As the basin gradually subsided, the sea encroached on wider and wider areas during Simpson, Viola, Sylvan and Hunton deposition. Deposition was continuous near the center of the basin but was repeatedly interrupted on shelf areas.

The entire region was uplifted in middle Devonian time. Hunton and all older rocks were bevelled, particularly to the north and northeast, exposing Precambrian rocks in places. Wheeler (1955) suggests that the Amarillo-Wichita trend was already a positive feature.

The siliceous shales of the Devonian-Mississippian Woodford Formation accummulated on this irregular surface. Sedimentation continued uninterrupted throughout the Mississippian. At the end of Mississippian time, epierogenic uplift again

occurred, seas retreated to the basin deeps and the top of the Mississippian was eroded. Many features that later became prominent began to develop as gentle folds and local warps. The Amarillo-Wichita arch was raised above sea level, separating the ancestral embayment into the Palo Duro-Hollis Basin on the south and the Anadarko Basin on the north. Late Mississippian or early Pennsylvanian Springer deposition, which was restricted to the deep part of the basin, was continuous with and in places overlapped by Morrow deposits.

The Anadarko Basin and the Amarillo-Wichita-Criner Hills uplift as they exist today, developed in late Morrow and Atoka time. This tectonic activity, known as the Wichita Orogeny, raised the Amarillo and Wichita Mountains along west-northwest trending high angle faults and developed a foredeep to the north creating the strong asymmetry of the Anadarko Basin. This fault system parallels older (pre-Mississippian) structural trends (Wroblewski, 1967) and consists of normal and high angle reverse faults.

The basin deepened rapidly during the Pennsylvanian period, marine deposition continued through Atoka and Des Moines time. Continued movement along older structures caused local thinning and onlap-offlap relationships within Atoka and Des Moines deposits. Coarse clastic rocks thin northward from the mountains, interfingering and grading into finer grained basin and shelf deposits.

A new system of faults developed that trend north 30° west, and cut older folds and fault systems (Wroblewski, 1967), these structures formedduring a period of down-to-the-basin normal faulting. A third episode of Pennsylvanian tectonic activity produced faults that trend north 45° east. These faults cut other Pennsylvanian faults, but may have been active in the pre-Pennsylvanian (Wroblewski, 1967).

The importance and persistence of old structures is demonstrated by the Ft. Cobb, Cordell, Sayre and Mobeetie features. These are pre-Mississippian faulted anticlines trending northwest that were again deformed during Pennsylvanian time. According to Wroblewski (1967) these structures may even be Precambrian.

Taken as a whole, the Pennsylvanian sets of faults of different trends do not show a consistent relationship one to another. This suggests that several, if not all, of the sets of faults moved intermittently over the same period of time. The implication being that these simultaneously moving faults are the product of the same stress field.

Renewed orogeny in late Pennsylvanian time rejuvenated older structures but deformation did not extend as far into the Anadarko Basin as did earlier activity. Missourian and Virgilian deposition was widespread and continuous into lower Permian. Clastic rocks consistently grade into finer grained basin deposits toward the north. By late Pennsylvanian times all but a few high peaks had been covered by the deposits.

During Permian time the basin gently subsided. It became filled and land locked and great evaporite sequences accumulated.

Triassic and Jurassic deposits consist of isolated evaporites and terrestrial materials that accumulated in an arid upland. Little remains of Cretaceous rocks which may or may not have once covered much of the region. Apparently, the entire area was elevated and tilted to the east during the Laramide deformation to the west.

Tertiary activity consisted of minor warping and the accumulation of terrestrial deposits.

The area has been relatively quiet in Quaternary and Recent times. A variety of alluvial materials, gravels, and windblown sands are the dominant sediment types to the present.

III. EVALUATION OF SKYLAB IMAGERY

FORMATS AND COVERAGE

Comparison of Image Scales and Formats

In the course of our Skylab project we used a variety of image formats including 70 mm, 5 in. and 9 in. transparencies and 9 in., 18 in. and 42 in. paper prints. Scales ranged from 1:950,000 to 1:100,000. Each format has its unique advantages and disadvantages. The smaller formats are certainly more convenient to work with and store. Whereas, the larger formats are better for display and compilation purposes, and the larger areas encourage a greater detail of delineation without magnification. The S190A 70 mm transparencies are in the easiest format to use with the I^2S adcol color additive viewer. This is the easiest format to store. Transparent enlargements (9" X 9") of the S190A and S190B imagery at scales of 1:700,000 and 1:500,000 respectively, are extremely convenient for interpretation in the laboratory. They fit easily on standard light tables and are easy to use with standard microscopes, magnifiers, and stereoscopes. The use of the stereoscope is exceedingly important because it provides a quantum increase in the confidence of the interpretation. This format is also quite easy to store. However, transparencies are not satisfactory for field work because of viewing problems, and field use (dust, static electricity and rough handling) degrades the image rapidly.

The level of detail interpretable on the 1:700,000 and 1:500,000 transparencies is about the same as that of the 1:100,000 paper prints. However, the space available on the 1:100,000 paper prints permits a greater level of detailed interpretation in some circumstances. No magnification is needed at 1:100,000.

We used paper prints of S190B photographs at scales of 1:500,000, 1:250,000 and 1:100,000. The 1:500,000 prints (9" X 9") are useful for laying out flight line indexes and for use with pocket stereoscope. The resolution is less than that of the transparencies at the same scale. This is also a convenient scale for field use. The 1:250,000 prints (18" X 18") are more bulky and somewhat less convenient for field use (but usable). This scale is extremely useful for laboratory interpretation and compilation because the need for magnification is infrequent, the photos match the scale of the 1° X 2° U.S.G.S. topographic sheets, and they can be used with mirror stereoscopes which permits matching topographic detail between map and image. The 1:100,000 prints (42" X 42") are too unwieldy for field use but excellent for compilation and detailed interpretation in the laboratory. Examination

of these images convinces us that for very detailed work the S190B imagery can be enlarged profitably to 1:500,000 or even larger (we have seen this done in several areas outside of our test area with very good results).

It is best, in regional projects such as ours, to interpret on the 1:500,000 scale transparencies and compile the results on the 1:250,000 paper prints. This statement assumes proper hardware, a transferscope in particular, is available and considers the advantages and disadvantages of the various formats. If appropriate equipment is not available for use of images at two or more scales, we found it best to perform all interpretations on 1:250,000 prints or transparencies. We also use the 1:250,000 paper prints for field checking our interpretations. For more detailed work in specific areas we recommend using larger scale transparencies and prints.

Comparison of Seasonal Coverage

Skylab provided insufficient frequency of coverage to allow a definitive comparison of the value of the imagery acquired during various seasons. Clouds and haze prevented acquisition of good imagery during the SL/2 mission and most of the SL/3 mission. 1973 was a particularly wet year and several times when Oklahoma was due for an overpass a front would move through causing considerable cloudiness throughout the area. Several cloud-free EREP passes were also pre-empted by other experiments and mechanical problems. Despite the perversity of the climate, SL/3 and SL/4 acquired several passes of substantially cloud-free imagery in the summer of 1973 and the winter of 1973-74. Imagery acquired during both these seasons is excellent for geologic interpretation.

Upon comparison, the imagery acquired on December 2, 1973 appears to be the best. Atmospheric conditions were excellent, the ground was snow-free and vegetation was at a minimum. When interpreted at a scale of 1:100,000 the detail in S190B photos is comparable to that of RB-57 photography at a scale of 1:118,000. However, as we point out in the airphoto-space photo comparison, certain lithologic features could be interpreted from the summer photo that could not be from the winter photo.

Imagery acquired January 30, 1974 was relatively cloud-free but the ground was covered with a light dusting of snow. We found that this light snow cover enhanced recognition of many structural features such as geomorphic anomalies and lineaments, but obscured tonal information that would suggest lithologic contacts and stratigraphic units.

The cloud-free portions of images from January 11, 1974 were heavily snow-covered. The heavy snow obscured most geologic features with the exception of sharp topographic breaks and topographically prominent linears.

Our conclusion, based on a limited amount of data, is that for photographic imagery of the type acquired by Skylab, late fall, winter or early spring imagery probably would be the optimum times of year to acquire imagery over an area such as western Oklahoma and the Panhandle of Texas for purposes of geologic interpretation. However, we are confident that imagery acquired at other cloud-free times of the year would add substantial and significant items of information to a geological interpretation. Thus, as we concluded in our ERTS study, we would strongly encourage anyone using space-acquired imagery for geologic interpretation to examine two or more coverages of imagery, preferably acquired during different seasons, in order to optimize the amount of geological information extracted.

COMPUTER PROCESSING OF DIGITAL DATA

For our purposes, one of the least successful portions of this study was the computer processing of the S192 tapes. Several factors lead to this judgement. There was a considerable amount of noise in the tapes, which interrupted the continuity of features and made any optical band-to-band operations very nearly worthless. The high quality, good resolution, convenience, and effectiveness of the photographic products for geological interpretation made the digital data less attractive than it may have been otherwise. Budget considerations made it undesirable to pursue digital processing in light of the above observations. Based on our discussions with other Skylab investigators, we decided not to attempt to use S193 data in our experiment.

We used S192 conical scan tapes (non-line-straightened) in order to preserve as much of the inherent accuracy and congruity of the scanner system as possible. For a test site we selected the bends of the Canadian River in Ellis, Dewey, Roger Mills, and Custer Counties, northwestern Oklahoma. This is an area where several Permian units, the Tertiary Ogallala and a variety of Quarternary units are exposed at the surface offering a wide variety of possible discriminations of surface materials.

Computer processing involved reformatting the data tapes, contrast enhancement of selected bands, and printing out the enhanced bands on a Litton recorder. We examined the enhanced images and attempted several types of photographic color composites. In general, the Permian redbeds can be differentiated from the younger rocks in bands six and nine and in the color composites. However, these distinctions and further differentiation are made more easily on S190 photographic products.

Data Tape Reformatting

The Skylab S192 data tapes received for analysis under this contract were conical scan data tapes containing samples of all the 22 scientific data output (SDO) channels. The data tapes had been processed by NASA to remove systematic "noise" from the data. The format of these data tapes is thoroughly discussed in NASA document PHO-TR543 entitled "Earth Resources Data Format Control Book."

The data format was an adaptation of "The Imagery Data Universal Tape Format." Because of the generality of the

design of the universal tape format, the first record on each tape was a header record used to describe the contents and data structure of the following video data.

The header record on each tape completely described the contents of the tape format of the remainder of the data tape. Among other information the header record specified number of SDO channels present, SDO channel numbers, spectral coverage for each SDO channel, the number of bytes of video per scan, the number of physical records per data set, the number of bytes of data per physical record, the number of SDO channels in the first record of data set, the number of SDO channels and all other records of the data set, number of bytes in ancillary block, byte address of the first block of video data, byte address of the calibration data, number of bytes of calibration data. The ancillary data block for each scanline included among other information, a tape line number and the latitude/longitude of the first center and last pixel of that particular line.

The planned utilization of the S192 digital data required that all of the scanlines for the entire test area sampled by a particular SDO channel be arranged sequentially on a single computer tape. The data reformat rearranged each individual original S192 data tape to the desired format.

During the data reformat process, the ephemeris data from the ancillary block was extracted from the data tapes and a printer listing of that data was produced. In addition, each SDO channel was histogrammed and a histogram printout produced. These data were useful in the later phases of the S192 digital data processing. The format of the reformatted S192 data tapes was designed to allow for convenient access and manipulation of the data while maintaining an efficient storage structure for the data. The first 32 bytes of data on each physical record, contained header identification information. Each block contained video data from a single SDO channel. The following information was stored within the 32 byte header of each phsycial record: SDO numbers for the SDO scans contained on that record, tape line number for that particular scan line, sequential line number starting at one for the first record on the tape, the total number of scans in that particular segment, the number of bytes of video data for each SDO (maximum of 1,240), and the input volume table serial number.

The physical records were arranged on the reformatted tapes according to SDO channels. Suppose that there were 560 lines contained in a particular original S192 data tape.

The first 560 records on the reformatted tape would then contain all of the video data for SDO numbers one through four. The five hundred sixty-first record was a separator record. Record numbers 562 through 1,121 would contain all the video data for SDO five through eight. This sequence continued until all of the SDO channels were transferred to the reformatted tape.

Contrast Enhancement

Selection of the spectral bands to be used on the test site was done by comparison of Litton prints from all of the spectral bands for the site. Through this process, spectral band 3 (.50-.56μ, blue), band 4 (.53-.61μ, green/yellow), band 5 (.59-.67μ, orange/red), band 6 (.64-.76μ red), and band 9 (1.00-1.22μ, infrared) were chosen because they appeared to give the best visual discrimination among several types of geologic features. Bands 3 and 4 are similar but do differentiate some soil types. After contrast enhancement band 5 appeared to be a poor choice and was not considered further. Band 6 and 9 were best for examining geologic and topographic features but not nearly so good as the photographic products from S190A and B.

While the spectral band selection was based on a pre-specified gray-level transformation, the operational gray-level set assignment was determined by gray levels found within the areas to be displayed. The advantage to this approach was that the data for each test site would be displayed with the maximum local contrast. A technique that is widely used and referred to in the literature as histogram equalization or histogram flattening was employed. Essentially, this procedure defines a non-linear, many-to-one mapping of input gray-levels to output gray-levels. The net effect is to spread the input data across the whole dynamic range of the output device.

The assignment of output gray-levels was a function of the frequency of occurrence of each input gray-level and the number of output values available in the test site. The tails of each histogram were clipped and only the gray-level interval of interest was contrast enhanced.

Results

The results of these operations were disappointing in comparison to the excellent photographic products acquired at the same time by the S190 instruments. However, the spectral resolution available in the scanner does hold out the possibility that in other areas and/or under

satisfactory operational conditions (less line noise in the data), computer manipulation of similar data could lead to rather sophisticated differentiation of surface composition units. Given the nature of our study and the level of effort required with the tapes, we concluded that computer manipulation of the S192 data is not time- or cost-effective in the Anadarko Basin for the purposes of geological exploration.

LITHOLOGY AND COMPARISON OF BANDS

S192 Multispectral Scanner

Comparison of lithologic interpretations made from film images of S192 scanner data shows that, in general, detail and variety of geologic information increase band by band from shorter to longer wavelengths. In the summary that follows no mention is made of bands 1 and 13. Band 1 was not recorded. Band 13 is so noisy for our passes that we found it useless. In fact, all our scanner data are noisy.

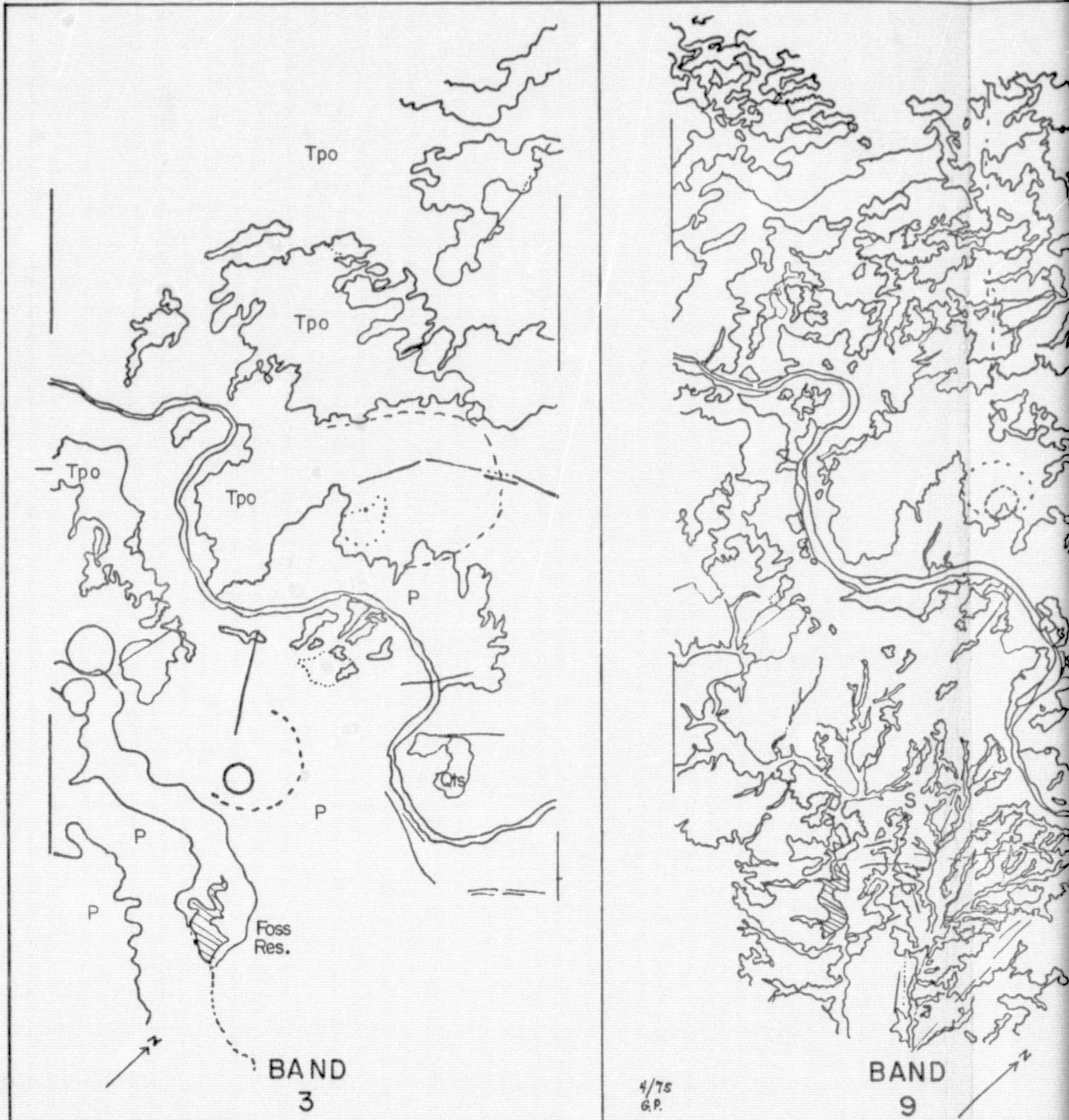
Bands 2 through 5 are best for speedy mapping of broad lithologic units. Major lithologic units of wide areal extent stand out because of a general lack of detail. Contrast is relatively low and much topographic and vegetative information is lacking or subdued. Roads and towns are distinguishable, but bodies of water are obscure. Cloud shadows are difficult to distinguish from permanent surface features.

Bands 6 through 12 provide significantly more detail than shorter wavelength bands and are generally of higher contrast. Major rock units are mappable but significant detail and additional units of more limited areal extent are apparent. This increased information content results from greater apparent vegetative and topographic effects on reflectivity at longer wavelengths, reduced atmospheric interference and much greater contrast between water bodies (including wet areas) and adjacent surfaces. Major streams and their larger tributaries standout because of good definition of topography, high contrast of water-filled channels and vegetative contrasts between alluvium and bedrock or residual soils. Even very minor drainage stands out on bands 11 and 12. The added detail at long wavelengths permits mapping of localized units, particularly those having good topographic expression.

Actual lithologic interpretations are compared in figures 2 and 7, and table 1 summarizes the general characteristics of S192 bands. By way of example, bands 3, 9 and 11 make a good, workable combination. Those bands are representative of the varying information content of S192 data as one goes from short to long wavelengths. Band 3 could be interpreted first to provide a basic lithologic picture of the area. Next, band 11 could be used to add detail, furnish additional lithologic information and map minor drainage and local, topographically expressed rock units. Last, band 9 could add information on alluviated areas and perhaps subdivide widespread units.

Group	Band-λ-SDO (μ)			Availability of Information	Notes on Miscellaneous Content		
A	2	.45-.51	18	adequate	roads and towns visible	water bodies indiscernible	maximum clouds + haze shadows poorly defined
	3	.50-.56	1	lowest	"	"	less haze problems cloud area still max.
	4	.53-.61	3	adequate	"	"	shadows poorly defined
	5	.59-.67	5	highest	"	water bodies poorly defined	"
B	6	.64-.76	7	good	roads and towns degraded	"	little haze clouds well defined shadows distinguishable
C	7	.73-.96	9	highest	"	water bodies well defined	minimal haze minimal cloud area shadows clearly defined
	8	.90-1.10	19	adequate	"	"	"
	9	1.00-1.22	20	adequate	little practical use for locating towns & roads	"	"
	10	1.10-1.35	17	lowest	"	"	"
D	11	1.45-1.80	11	preferred	major roads quite apparent	"	"
	12	2.03-2.38	13	adequate	"	"	"
E	13	10.00-12.70	21	poor	------	------	------

Table I . Summary of S192 scanner film image characteristics. GROUP refers to similarity of geologic information recorded in images. BAND-λ-SDO lists bands by number, wavelength and digital tape track number used for recording each band as supplied to Principal Investigator. "λ", as listed, was determined by inspection of sensor response curves and varies from nominal list supplied by NASA. AVAILABILITY OF INFORMATION refers to a visual inspection in which bands were ranked by ease of interpretation, which depends on contrast and gray level separation and resolution. A preferred working set of images would therefore consist of the best band from each of the groups, with band 13 added where noise content is low.



Lithologic interpretations of northwestern Oklahoma were made from 126
scanner data. Compare to state geologic map of the area (map 3). Ba
range of information and detail provided by the S192 scanner. Refer t
provides a quick reconaissance geologic map of the area. However, con
show up. Foss Reservoir is almost unrecognizable as a body of water,
area and the context of the lake. Tertiary strata (Pliocene Ogallala)
maps. <u>Band 9</u> provides so much detail that some major units are obscur
enhances alluviated stream valleys (S) thereby adding significant data
<u>Band 11</u> also shows a complex Ogallala formation. Contacts are more pr
sand (Qts) is mapped on 11 in one of the Canadian River bends reinforc
than adding new information at this point apparently adds confusing de
Drainage analysis is best done on 11 even though alluviated areas are
anomalies are also shown on these interpretations.
P = Permian undivided; Tpo = Pliocene Ogallala formation; Qts = Quate

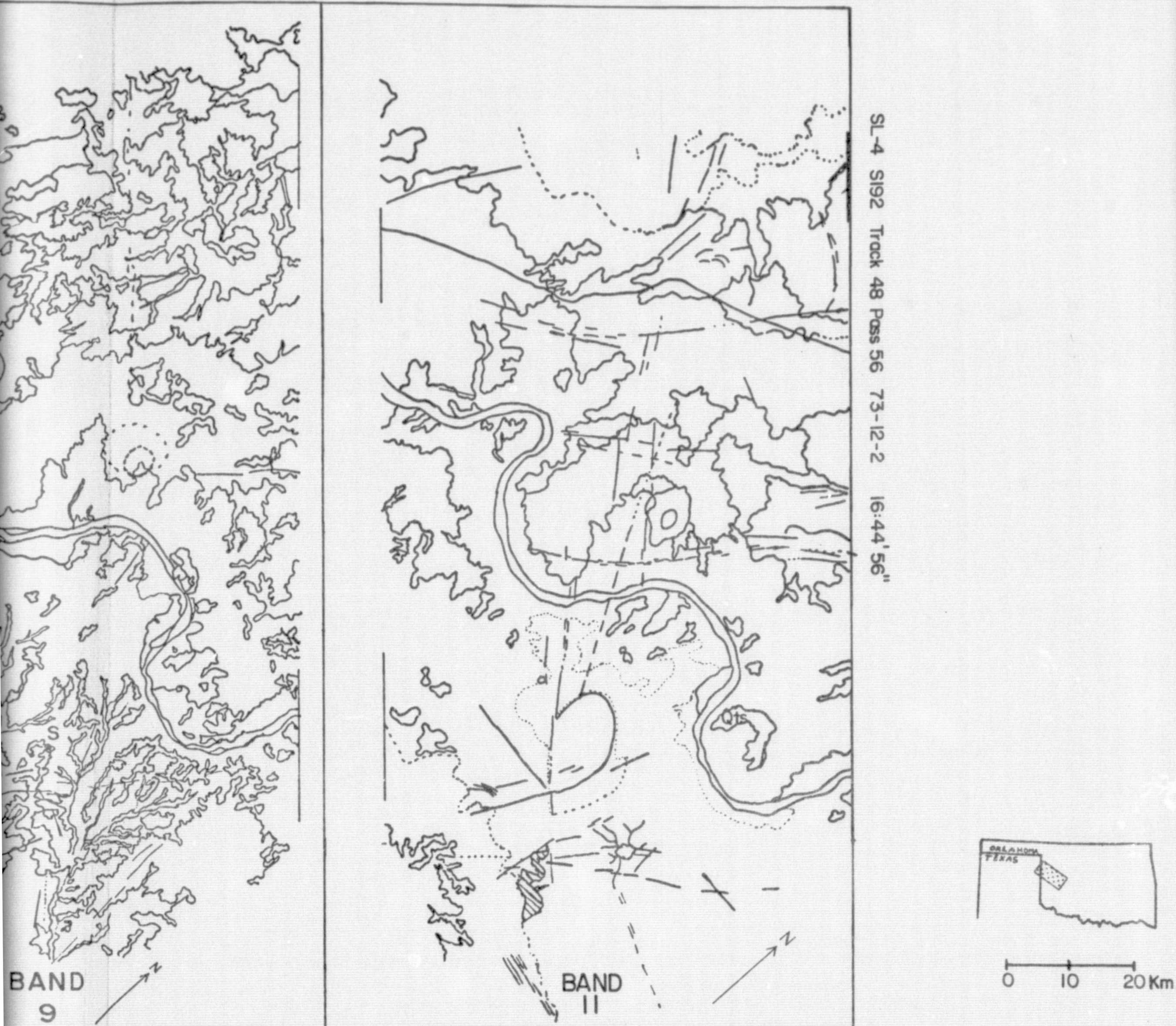
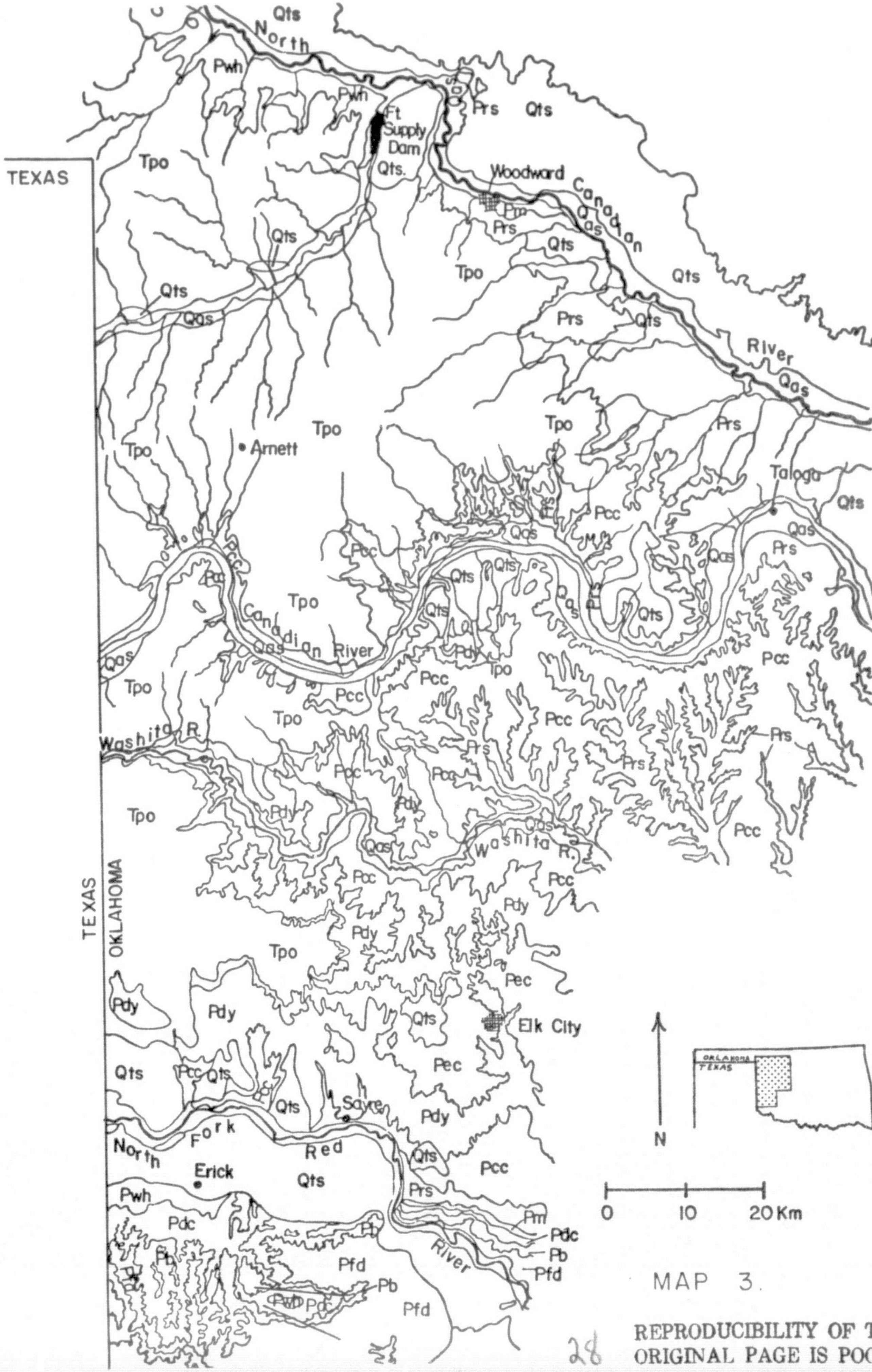


Figure 2 .

e made from 126 mm (5 in.) film positives of S192 multispectral
a (map 3). Bands 3, 9 and 11 were chosen to demonstrate the
anner. Refer to groups "A", "C" and "D" in Table I . Band 3
. However, contacts lack detail and alluviated areas do not
body of water, save for the interpreter's experience in the
ocene Ogallala) show a complexity not indicated on existing
nits are obscured, particularly the Ogallala. 9 certainly
ignificant data and details. Foss Reservoir is easily mapped.
cts are more precise and detailed than on band 3. A patch of
bends reinforcing the interpretation on 3. Band 9, rather
ds confusing detail. Topography is emphasized on band 11.
ated areas are not enhanced as on band 9. Several linears and

n; Qts = Quaternary terrace sand.

FOLDOUT FRAME 2


TEXAS
OKLAHOMA
North Canadian River
Ft Supply Dam
Woodward
Arnett
Taloga
Canadian River
Washita R.
Elk City
Sayre
Erick
North Fork Red River
Qts
Qas
Pwh
Prs
Pm
Tpo
Pcc
Pdy
Pec
Pdc
Pb
Pfd
N
OKLAHOMA
TEXAS
0
10
20 Km

MAP 3.

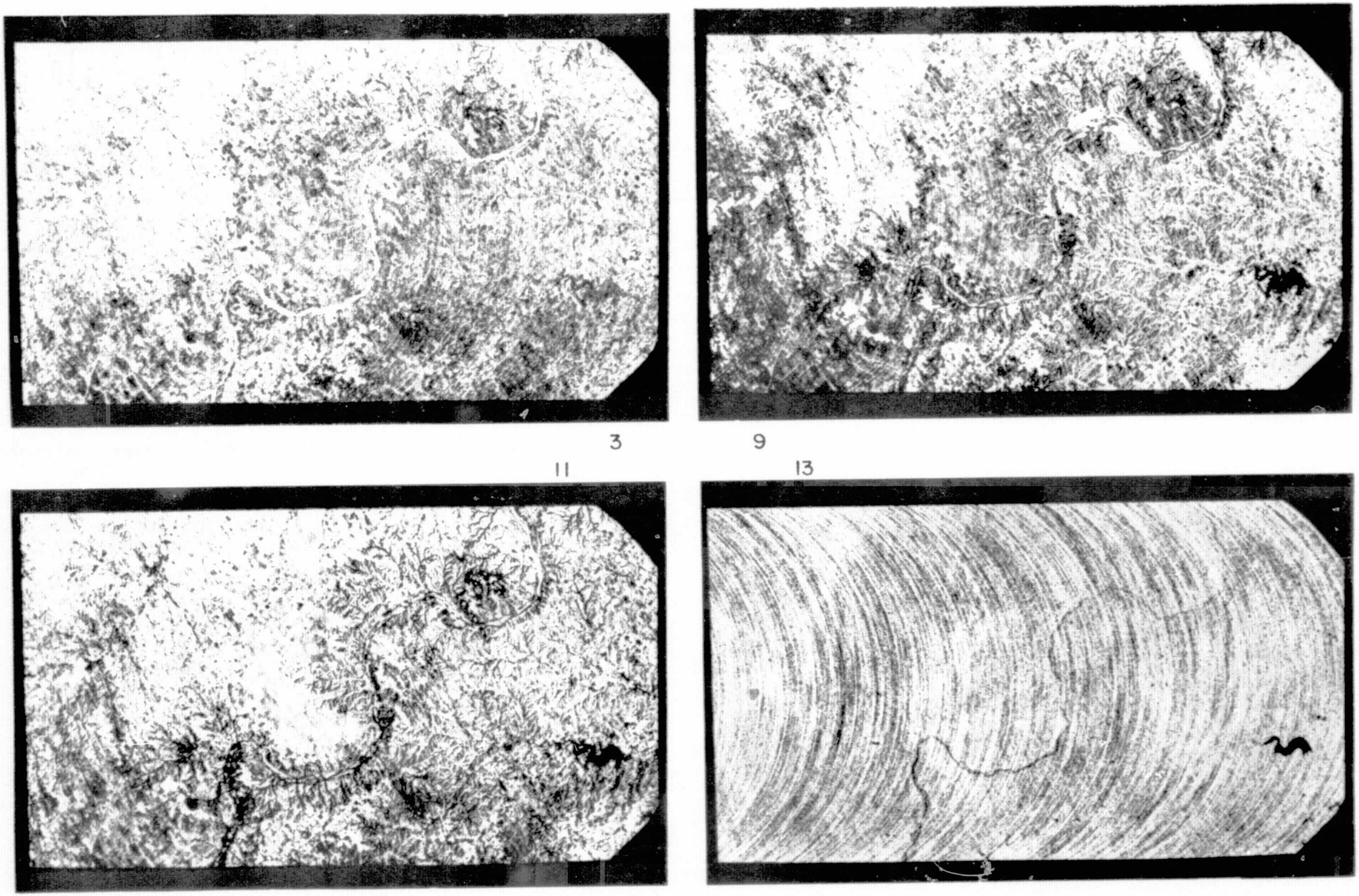


Figure 3 . Comparison of S192 bands 3, 9, 11, 13. The interpretations in figure 2 were made from these scenes.

S190A Multispectral Camera

Lithologic information in S190A multispectral photos varies greatly from band to band. Refer to figure 5 . Variations in grain and contrast, as well as variations in spectral response, significantly affect geologic content. The two black and white infrared bands contain the least amount and variety of useful information. The red band and the normal color band provide the greatest variety of easily interpreted geologic data. All bands contain some unique information or some information that is most readily apparent when compared to the other bands.

Infrared Bands (black-and-white):

The two black and white IR bands are similar. They show well only the grossest features such as major streams and lithologic units of great areal extent and/or strong contrast. Cultural features, except for large fields, generally are not resolved, making it difficult for the user to orient the image and locate features of interest.

These bands are best used to provide a reconnaissance base for detailing on the other bands. Major linear zones and tonal features and major lithologic units of high contrast can be sketched on an overlay. The overlay can then be used as a guide when interpreting features that are less apparent or that are shown in more detail on other images.

One example of such useful information is the Permian Elk City-Doxey contact. The Elk City unit is highly reflective at infrared wavelengths. It contrasts well with the underlying Doxey shale and can be quickly mapped. Contrast is lower but adequate for mapping purposes on color infrared. However, the contact must be mapped almost solely by subtle textural contrasts on the other three bands because there is little tonal contrast.

There are also several linear features that are unique to IR photos or are more visible in infrared than in other wavelengths. A zone of short linears and tonal contrasts extends N50E from near Grand Oklahoma in Ellis County for more than 30 km. See figure 4. The zone appears on Landsat as a single line. It was also mapped from the S190A green band as a fracture zone but is lacking from or was overlooked on other bands. This zone seems to be associated with a buried Paleozoic fault. It coincides with structure expressed as a change in strike of Virgilian rocks (uppermost Pennsylvanian) and as an isopach thick in Missourian rocks (lower upper Pennsylvanian).

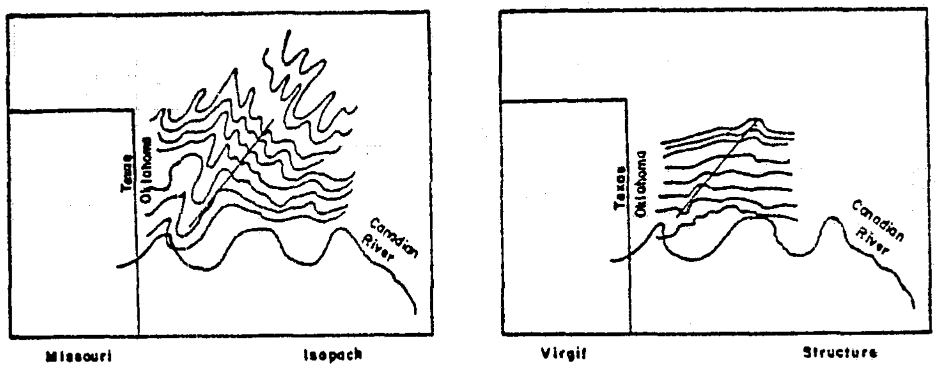


Figure 4 . The S190A black-and-white infrared bands are valuable for interpretation of linears. Linears are few on these two bands, but most of them are unique. Two linears of particular interest occur at Canadian in the Texas Panhandle (not shown) and in Ellis County, Oklahoma (above). This linear and others parallel to it are related to subsurface features. As shown here the linear is related to upper Pennsylvanian sedimentary and structural features.

The black and white IR photos distinguish well between alluvium and Permian units. Permian Elk City, Pliocene Ogallala and Quaternary sand and alluvium all contrast strongly with Permian rock units. Unfortunately, the Pliocene and Quaternary units do not contrast with each other and where they are adjacent or overlapping, contacts are obscure and they cannot be mapped separately.

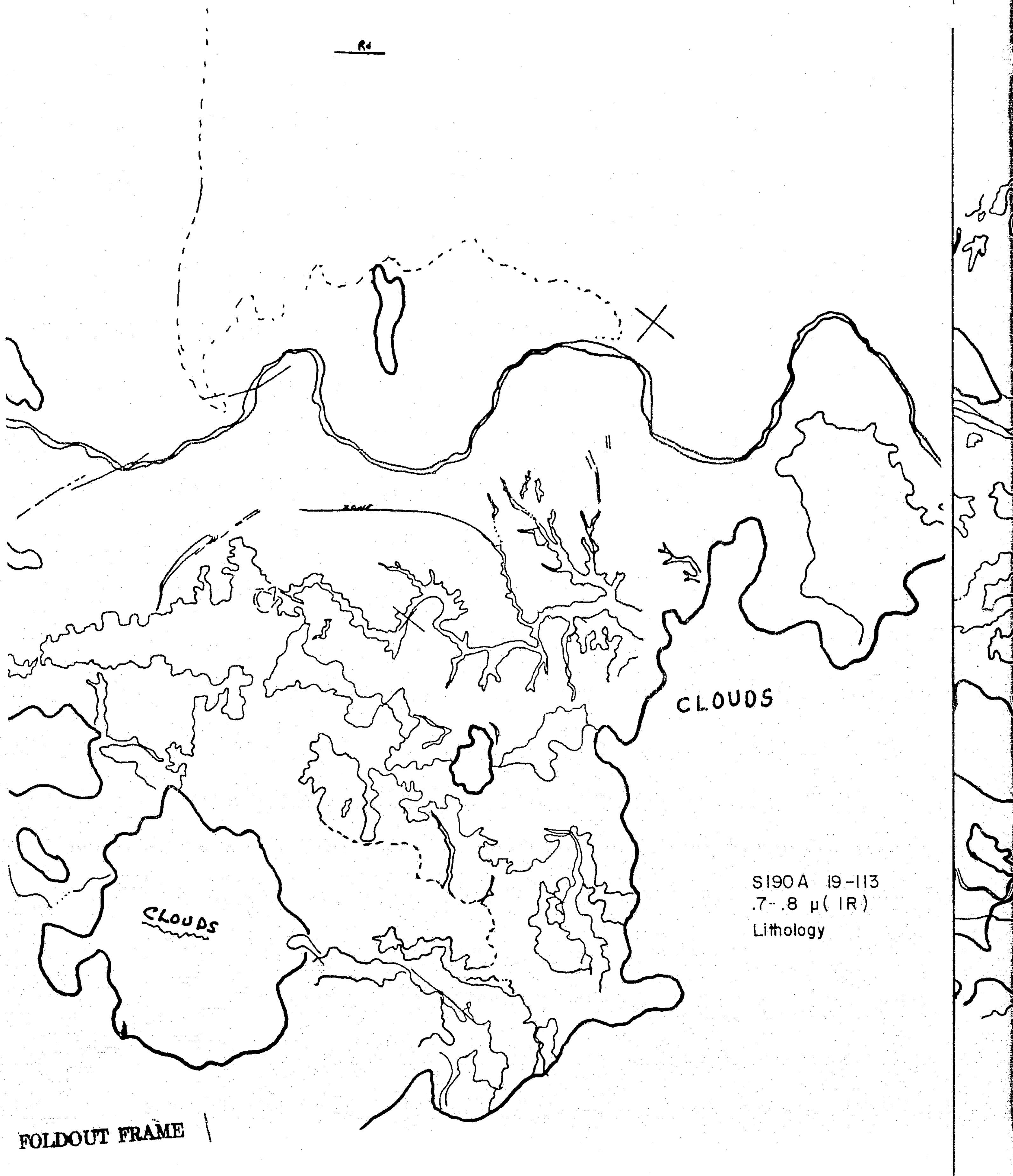
Green Band:

The green band shows much more detail than the two IR bands just described. There is good separation of Ogallala and Quaternary deposits from Permian rocks. This band shows Ogallala and Quaternary as distinct units in some areas but they blend together at other places. Moisture, vegetation and topographic differences seem to account for the variation in contrast between Quaternary and Tertiary units. This variation in contrast tends to reinforce the notion that satellite coverage during different seasons is valuable for geologic interpretation.

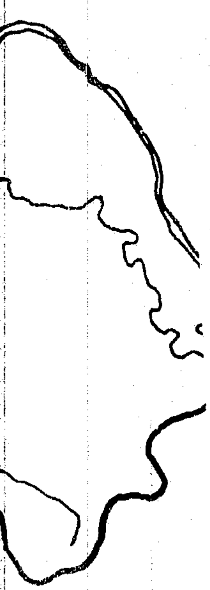
Permian units are essentially indistinguishable from one another except in an area south of Taloga in Dewey County, Oklahoma where Cloud Chief and Rush Springs are distinct on most images. The green band gives less detail than the remaining bands. Contacts are less detailed and less exact and units are fewer (more generalized) than on the bands discussed below.

Color Infrared Band:

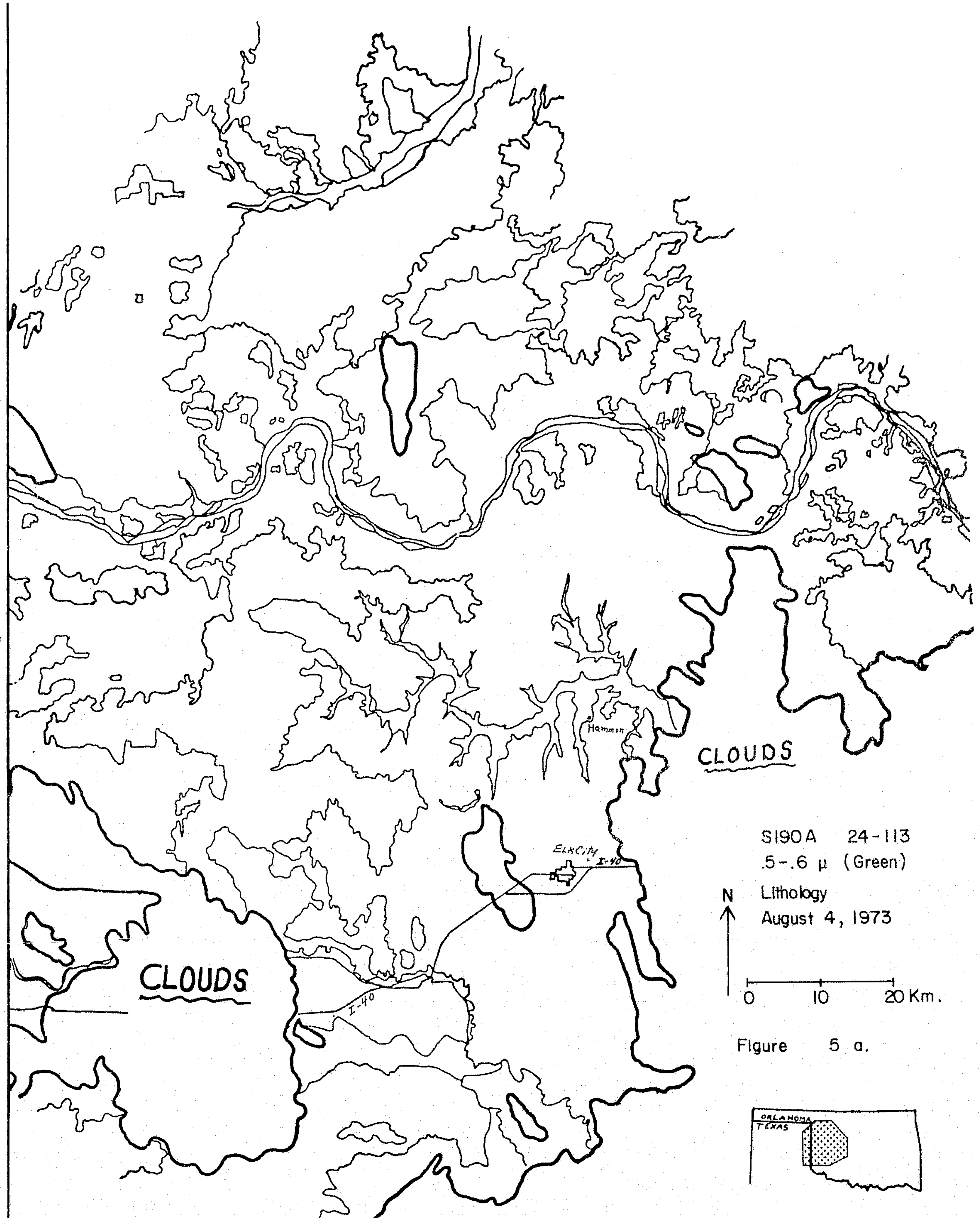
The S190A color IR film is grainy. Contrast is low to



FOLDOUT FRAME

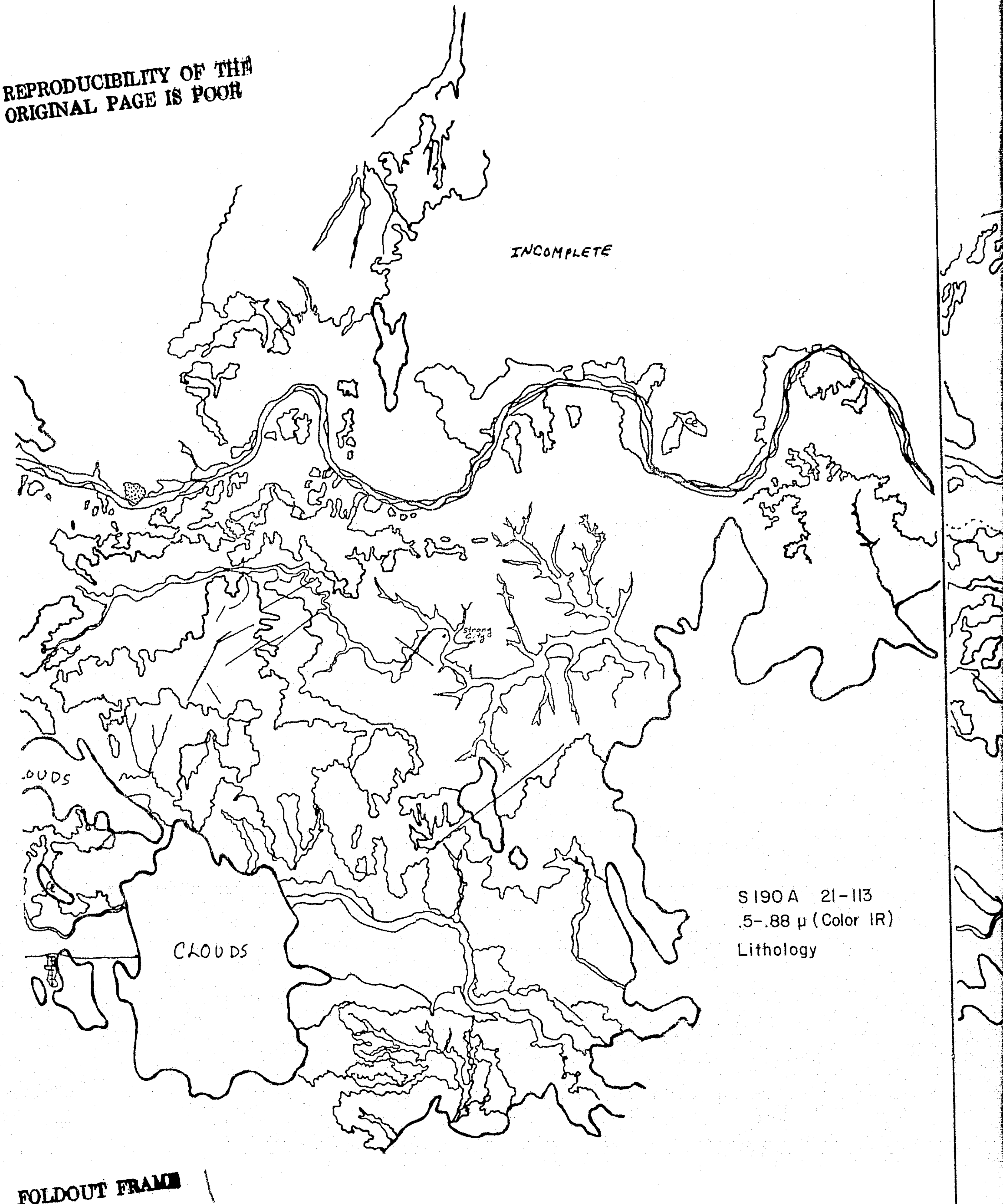


19-113
(IR)



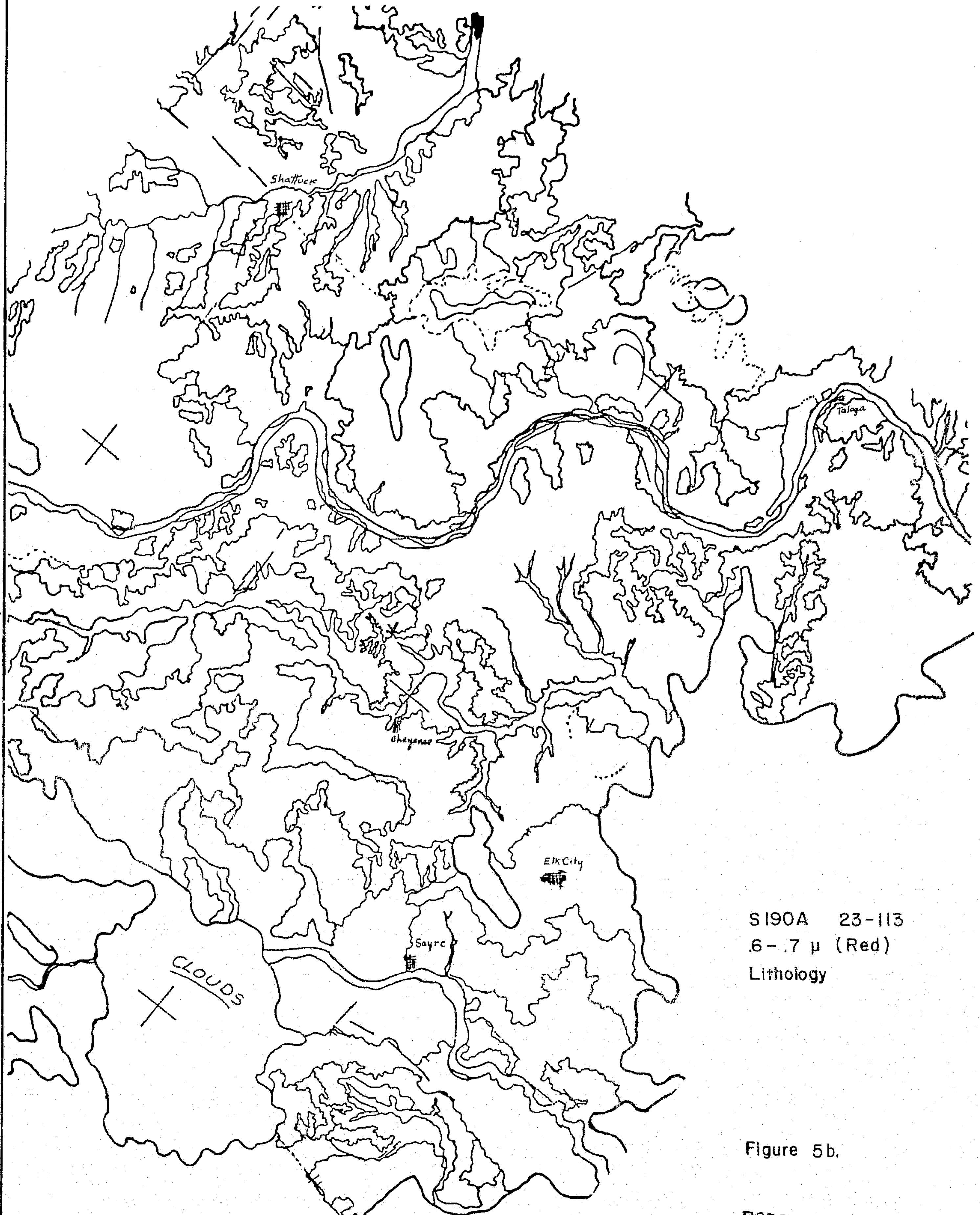
CLOUDS
Hammon
ElkCity
I-40
CLOUDS
I-40
S190A 24-113
.5-.6 μ (Green)
Lithology
August 4, 1973
N
0 10 20 Km.
OKLAHOMA
TEXAS

Figure 5 a.



S190A 21-113
.5-.88 μ (Color IR)
Lithology

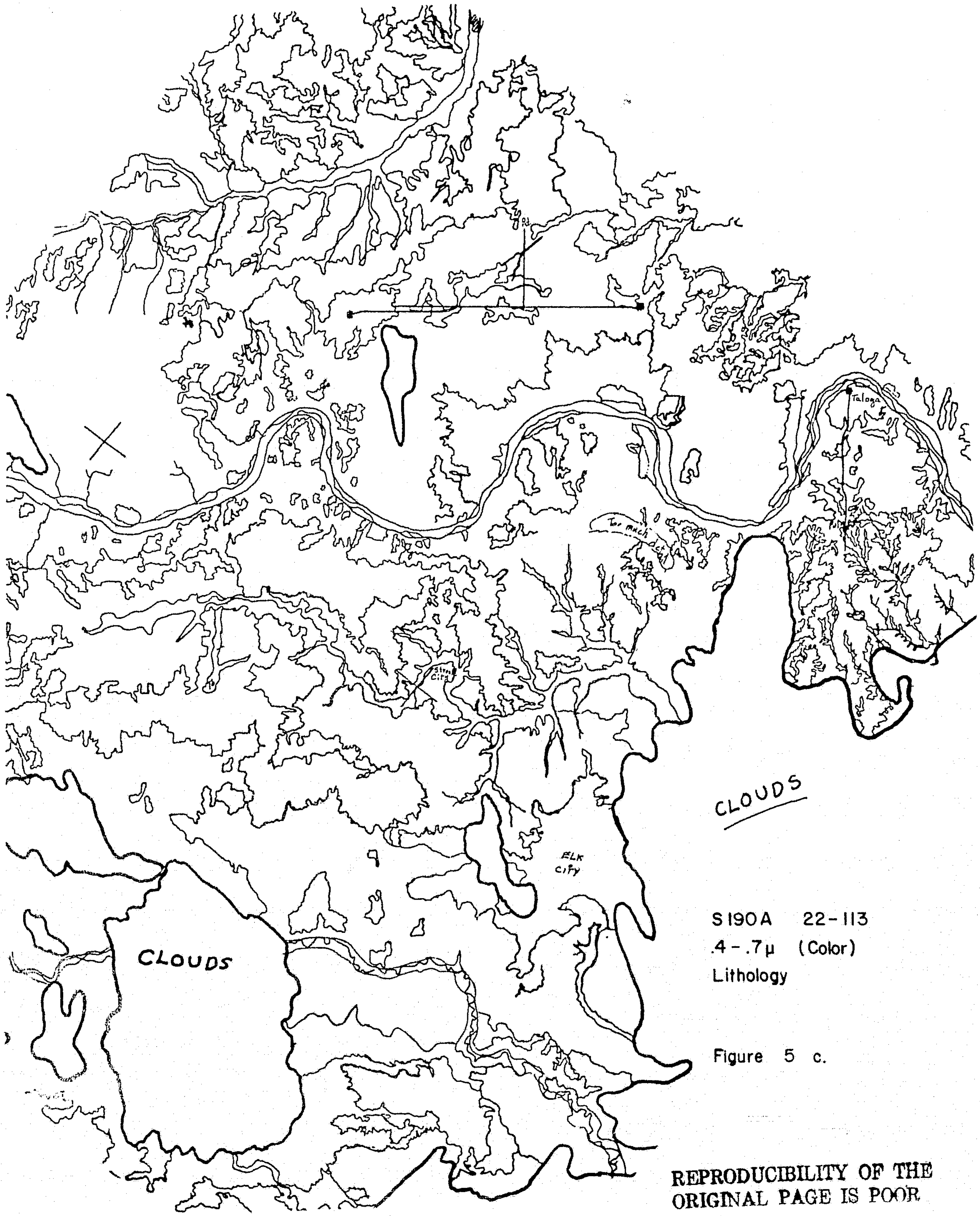
21 – 113
(Color IR)



S190A 23-113
.6 - .7 μ (Red)
Lithology

Figure 5b.

FOLDOUT FRAME



S190A 22-113
.4 - .7µ (Color)
Lithology

Figure 5 c.

moderate and our passes were either overexposed or underexposed. Resolution is medium relative to the other bands. Certainly, color is a distinct advantage, compensating to a degree for rather poor resolution and contrast.

Lithology inferred from color IR is a good match for the state geologic map. Quaternary sediments are distinct from Permian rocks. In several locations, contacts within Permian rocks can be mapped in detail. The same contacts are unresolved in other locations.

Red Band:

Red band photos are high contrast and high resolution images, superior in both qualities to all bands except the full spectrum color film. Many rock units were mapped from red band photos that are not recognizable on the other bands. Great accuracy and fine detail were achieved when interpretation was done from this band.

For example, we can easily map terraces, inactive bed deposits, active channels and Quaternary alluvium along the course of the Canadian River. The alluviated valley of the Washita River was mapped in greater detail and farther along its course than on any of the other bands. Tertiary (Ogallala) deposits were easily mapped.

Most important of all is the fact that several Permian units are distinct one from the other at many places. Rush Springs Sandstone is distinct from Cloud Chief rocks in Dewey County. Whitehorse, Cloud Chief and Rush Springs are distinct south of Sayre in Greer County. Doxey and Cloud Chief can be mapped in the area of Strong City, Oklahoma. This is the area referred to in this report in the section comparing airphotos and space photos. This contact cannot be mapped from any S190A bands except the red band and the color photos. It cannot be found on one S190B pass and can be delineated only with close inspection of another S190B pass made on a different date.

Color Band:

The color film has contrast equal to that of the red band. It has the finest apparent resolution, by far, of all S190A bands.

Much of what has been written above concerning the red band can be reiterated here. Many rock units are recognizable, including the Doxey-Cloud Chief contact near Strong City. The excellent contrast and resolution permit finer detail and even greater accuracy than the red band.

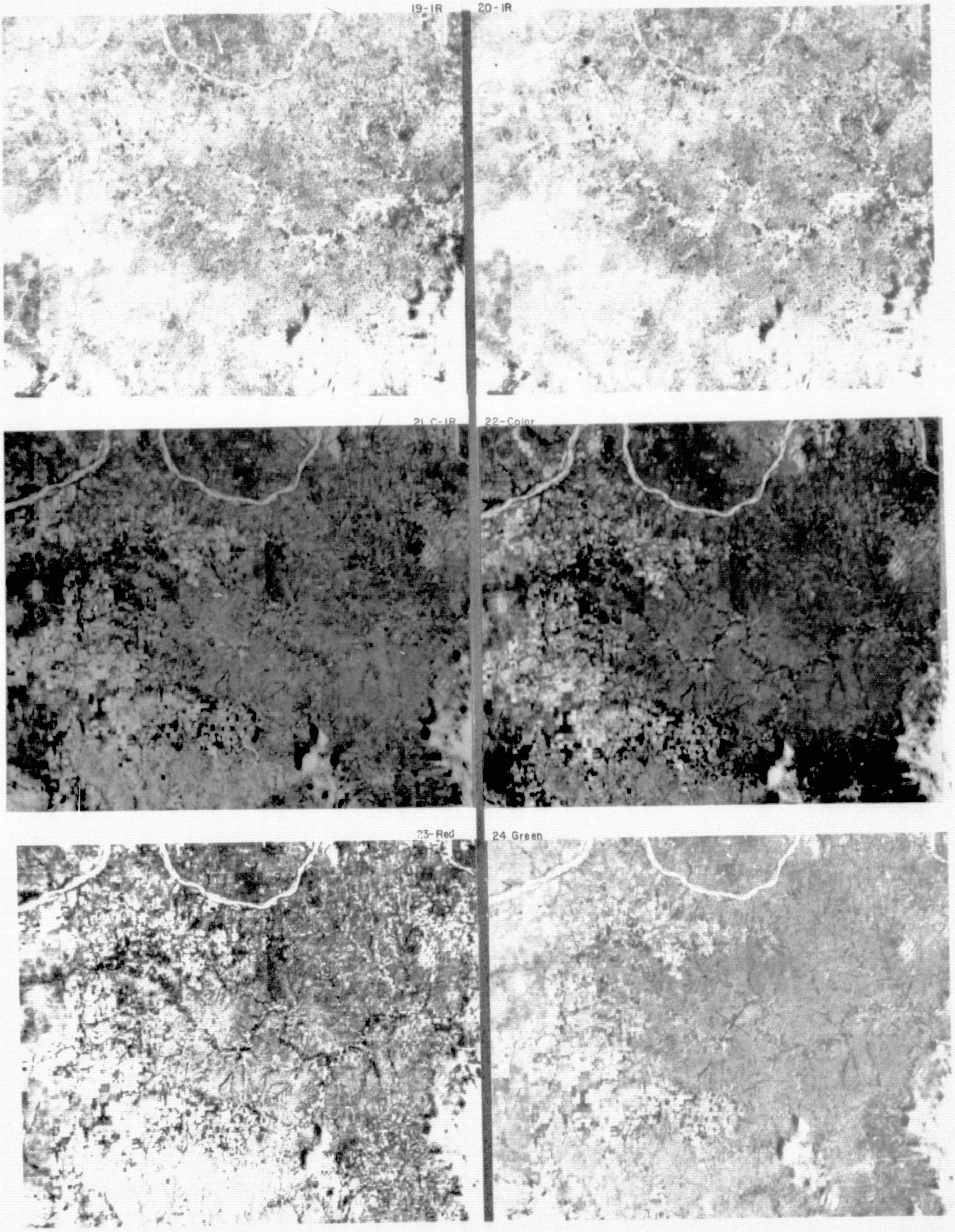


Figure 6. S190A photos rolls 19-24, frame 113.

Moreover, use of color enhances most features and reduces recognition time, increasing confidence in the interpretations made from these photos.

S190B Earth Terrain Camera

S190B photos have the highest resolution of all Skylab images. The high resolution color film combined with an 18 in. focal length lens system makes S190B photos superior to the other systems for almost all geologic applications.

Drainage and fracture studies can be done precisely from enlarged S190B photos. The same kinds of analyses are possible from the other sensors but can be done only as first, rough studies to be followed by more careful analyses on S190B.

Lithologic contacts can usually be mapped in fine detail and located within 100 ft when compared to large-scale maps. In this respect, it is instructive to compare figure 8 with figures 5a,b,c. However, the Doxey-Cloud Chief contact studied in the airphoto-space photo comparison was not traced on S190B 90-145. It was traced with difficulty on S190B 83-046 only after the experience of the airphoto interpretation. This demonstrates again the value of multiple coverage. The contact was traced with relative ease on two bands of S190A acquired simultaneously with 83-046. These studies indicate that very high resolution (airphoto) and/or multiband capability (S190A) can compensate in some cases for lack of repetitive and/or multi-seasonal photo coverage.

Strike and dip measurements and approximations can be done in many locations on S190B. Faults and, in some instances, joints can be traced and studied in detail. Their location can be determined precisely on S190B. Structural interpretation can also be done from the other sensors, but frequency of proper conditions and precision in locating points are more limited than on S190B. S190A and S192 are, perhaps, more useful for regional studies than for studies of restricted areas or individual prospects.

One disadvantage to using S190B is its high resolution compared to S190A, S192 and Landsat. One rationale for using satellite images is the fact that some features are best seen when distracting detail is eliminated, or when several subtle features are integrated by lowered resolution. S190B photos actually "hide" some potentially significant features amid the "noise" of detail.

General Comments and Summary

Most lithologic units can be mapped in detail and precisely located from S190B. Because of its high resolution, S190B is superior to S190A and S192 for most geologic applications. High resolution and lack of multispectral images are disadvantages compared to S190A, S192 and Landsat images in applications where low "noise" content is desirable.

An orbital perspective and high resolution give S190B advantages over high altitude photos. No mosaics are required. Proper enlargement eliminates the need for magnification. Geologic features can be viewed and studied in a regional context. Lower resolution than airphotos is a disadvantage in specific applications where precise analysis is necessary.

Lithologic units mapped from S190A photos correspond closely with units on existing geologic maps. The red and the color bands generally have the closest similarity to existing maps and the similarities extend along greater distances than on other bands.

Lithologic interpretations from S192 scanner images also correspond well with existing maps. Best results are obtained when interpretations of several bands are combined. The scanner data contain abundant electronic noise and have poorer resolution than the camera data. As a result, scanner images are less valuable for petroleum exploration than are the photos.

As important as the demonstration of the ability to accurately map known rock units, is the ability of space imagery to alter existing maps. Our Skylab studies have reinforced our belief that the Ogallala formation can and should be remapped. Every band shows new "image units" within the Ogallala north of the Canadian River. There is also a band-by-band persistence of a boundary within the Ogallala south of Cheyenne. Permian contacts cannot be distinguished here but, the Ogallala as seen from Skylab is certainly not as uniform as mapped in this area. The patch of "Quaternary sand" mentioned in our ERTS report (Collins, 1974, p.80, figure 15) as being similar to Ogallala appears similar as well on Skylab S190A and B and S192. A field check of the area prompted by our remote sensing studies has provided fossils of possible Tertiary age that now are under study. S192 images indicate that further mapping is warranted in the Duncan, Oklahoma area. For here, scanner images extend the Permian Hennessey shale far southeast into a unit mapped as Permian Marlow. Refer to figure 7 .

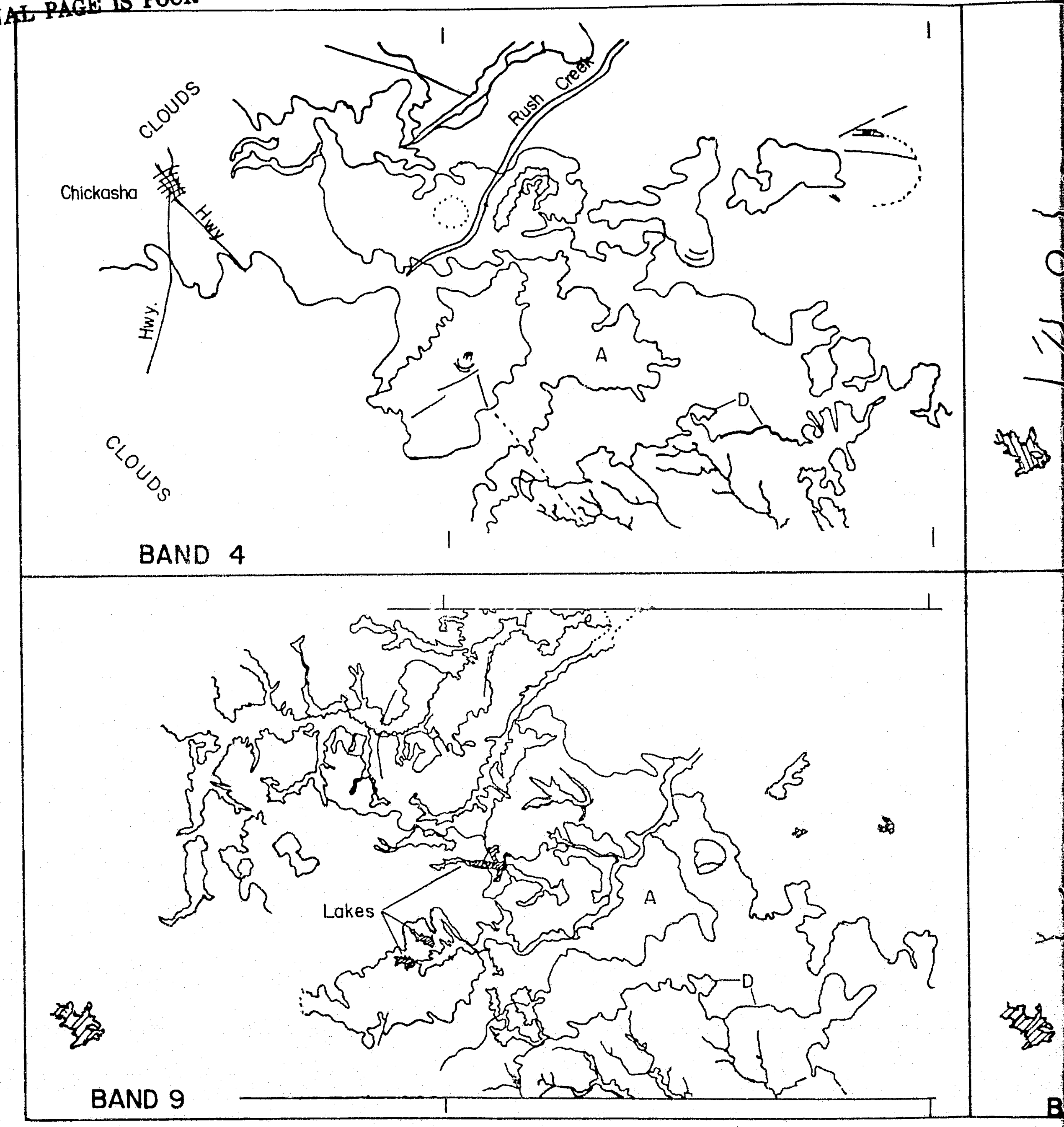
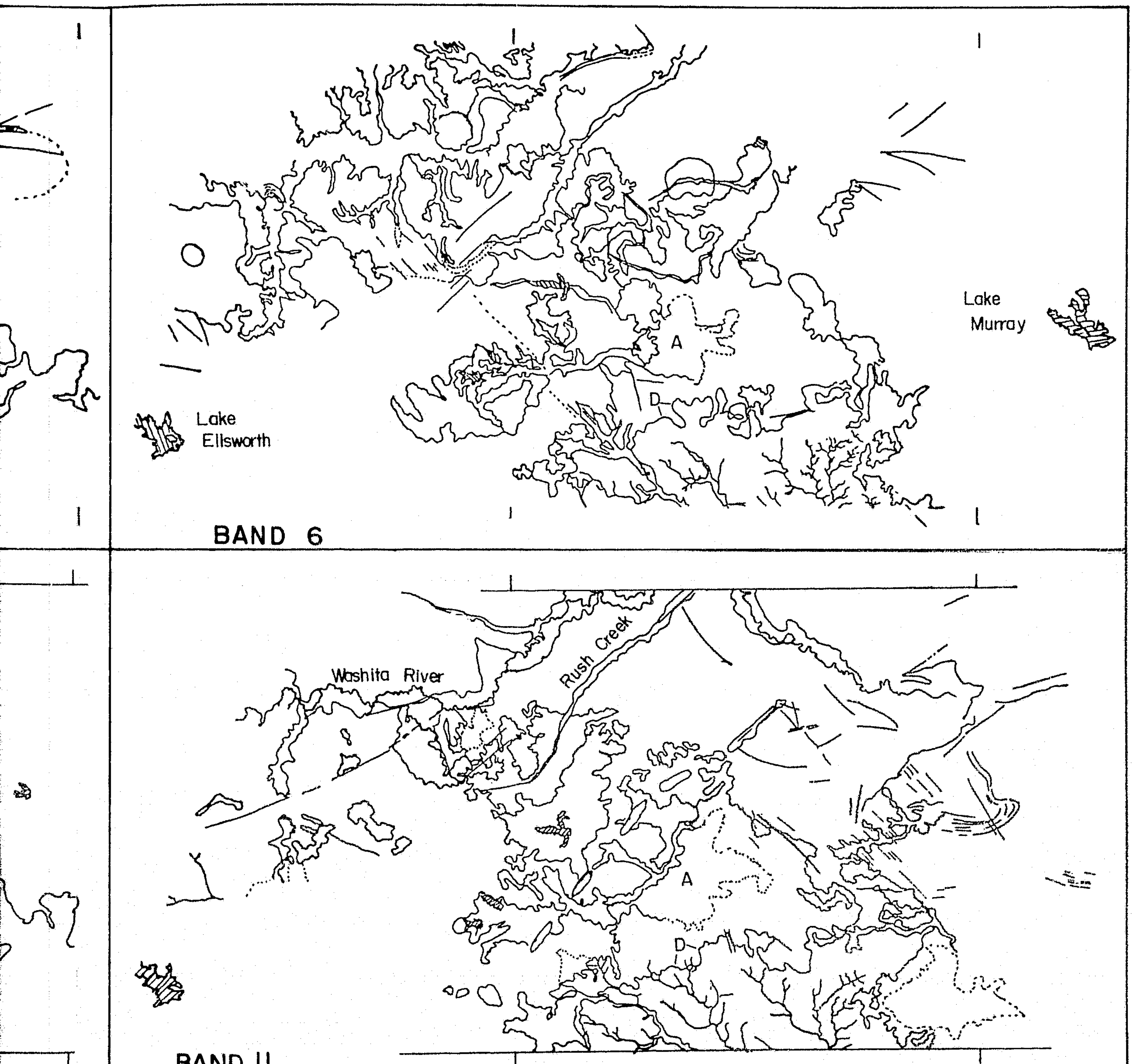
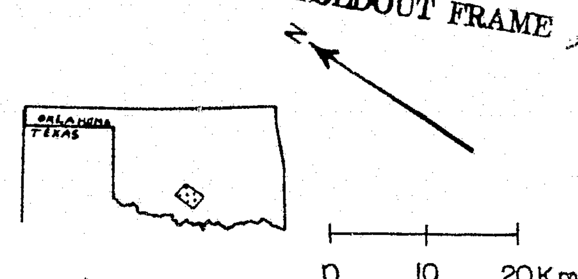


Figure 7. Area "A" on the interpretations is equivalent to and continuous state map shows (see map 4) this area is underlain by the Wellington form throughout the S192 spectrum strongly suggests that the area should be field in some places contact "D" approximates sandstone bed "t" as interpreted on and "t" are widely divergent. Skylab and Landsat scanner images show that t morphic areas. The state geologic map shows distinct Garber and Wellington inction is lost as one follows these units south and west until only the Wel data suggest possible remapping is in order, its aim being to subdivide the for another discussion of features "A" and "D". The S192 scanner bands in t the same range of geologic content as do bands 3, 9, 11 in figure 2 .

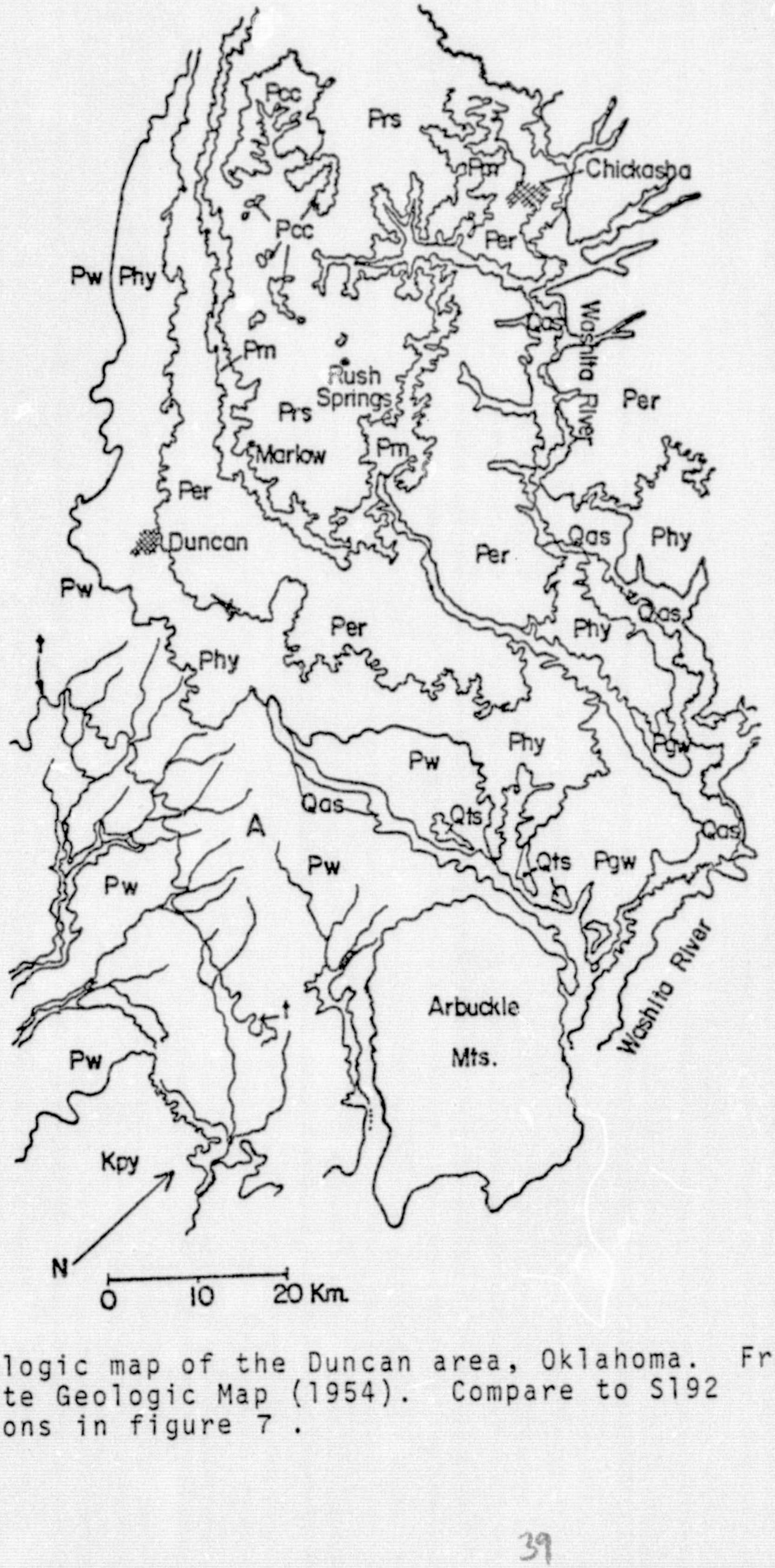


SL-4 S192 Track 48 Pass 56 73-12-2 16:45'41"

FOLDOUT FRAME 2



and continuous with Permian Hennessey shale. However, the
Wellington formation. The persistence of this "image unit"
should be field checked for possible remapping. Likewise,
interpreted on the state geologic map. At many places "D"
ges show that this "contact" separates two distinct geo-
and Wellington formations in central Oklahoma. The dist-
il only the Wellington is mapped in the Duncan area. S192
subdivide the Wellington. Refer to page of this report
nner bands in this illustration: 4, 6, 9, 11, demonstrate
gure 2 .



Map 4 . Geologic map of the Duncan area, Oklahoma. From Oklahoma State Geologic Map (1954). Compare to S192 interpretations in figure 7 .

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Last, it should be re-emphasized that each band contains unique information. Although certain sensors and bands will be chosen to give the best results in the shortest time, no study can ignore the contributions of the remaining bands. This is particularly true in cases where a detailed study is being made of a restricted site or delimited prospect to maximize an understanding of the local geology.

COMPARISON OF SKYLAB PHOTOS AND AIRPHOTOS

Photographic products collected by aircraft and by Skylab were compared. In particular, a careful comparison was made of photos recorded over the Hammon, Oklahoma area. Table 2 lists pertinent information on the color airphoto and S190B color photo.

	Airphoto	Space Photo
Camera	RC 8	S190B Earth Terrain Camera
Lens	6 in.	18 in.
Film	SO-397	SO-242
Filter	2A	#5 neutral density
Format	9" transparency	40" print
Scale	1:118,000	1:100,000
Mission	236	Skylab 4
Date	April 27, 1973	December 2, 1973
Time	2100 GMT	1646 GMT
Sun Azimuth	242°	219°
Sun Angle	50°	35°
Cloud Cover	10%	<1%

Table 2. Data on photos used in comparison of airphoto and S190B photo.

Linears Compared

The orientations of linears as interpreted from both photos are similar (table 3). Even the total numbers would probably be nearly the same were there no cloud cover on the airphoto. The average length is significantly greater on the Skylab photo. The greater apparent length results from the greater exposed (cloud free) surface, higher contrast on this particular S190B photo, and especially from the integrating effect of the regional view and lower resolution of the space photo. It can also be seen that relatively few of the linears are common to both photos. This general lack of correspondence indicates the value of integrating two or more kinds of imagery to form an accurate, reliable analysis. Some features interpreted as linears from Skylab can be eliminated as having no geologic basis when referred to airphotos of the same scale. On the other hand, some linears that result from integration of several distinct features when viewed from orbital altitudes are not readily perceived on airphotos and may go undetected without the contribution of space photos.

	Number of Linears	Average Length	Orientations
S190B	334	.7 km (2264 ft.)	
Airphoto	285	.5 km (1608 ft.)	
Common	75	Not recorded	

Table 3. Comparison of linears interpreted from S190B (90-145) and high altitude airphoto (mission #236, 01-113). The number of linears as shown is unique to each photo. We listed 409 total linears on S190B and 360 on the airphoto.

We have made other, less rigorous comparisons of linears as seen on air photos and space photos, including one reported earlier (Collins, et al., 1975b, p.13). These comparisons used Skylab photos at much smaller scales (1:250,000; 1:490,000 and 1:770,000) than the airphotos (1:110,000). In general, we found that: 1) use of small-scale images reduced the number of linears visible on the photos. 2) The same trends predominate on all images, indicating the relatively high sun angles and variable azimuths have a minor effect on visibility of linears in the study site. 3) The number of linears common to two or more images is a somewhat higher percentage than the figures given above in table 3 . 4) The large areas covered by Skylab photos give them advantages in regional analysis.

Lithology Compared

Lithologic interpretations from Skylab photos are generally accurate, detailed and complete when judged by regional geologic maps. The overall structural and lithologic features of the Anadarko Basin are visible in S190A and S190B multiband photos. Important details, however, frequently are not recorded. Detail is lost mainly by lower resolution from orbital altitudes and lower color contrast. Some lithologic units can be distinguished from photos only by subtle textural or color contrasts. Such subtleties are easily lost on orbital imagery. For example, in Washita County, Oklahoma, the Permian redbed units Elk City, Doxey, Cloud Chief and Rush Springs can each be mapped on S190B mainly because the topography, texture and land-use practices are distinct for each unit. Color contrast is low but distinguishable and is enhanced by the factors just listed. Unfortunately, these major units could not be mapped from S190B 90-145 in the eastern half of Roger Mills County near Strong City, Oklahoma. See figure 8 . A later attempt to map these contacts used

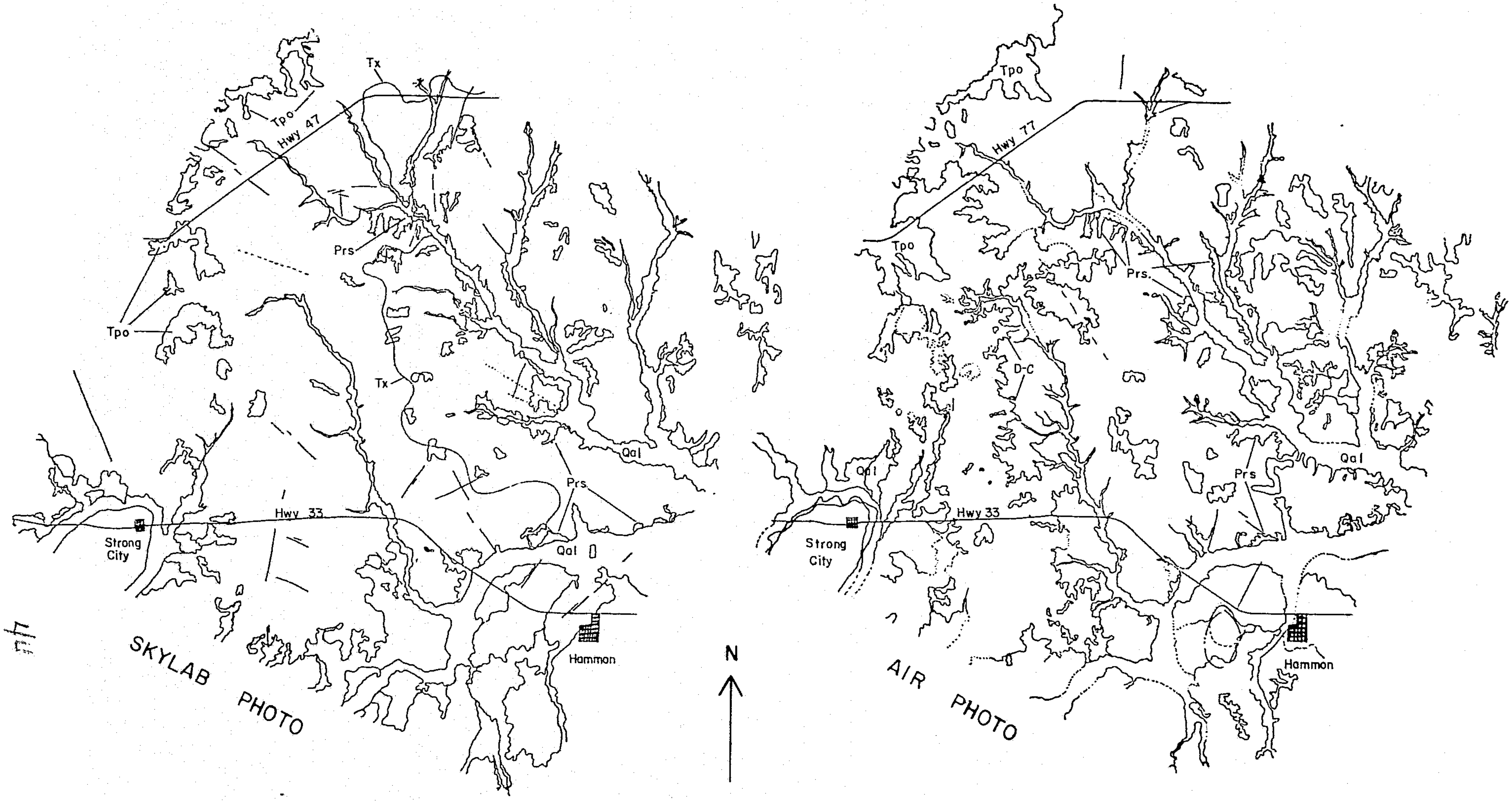
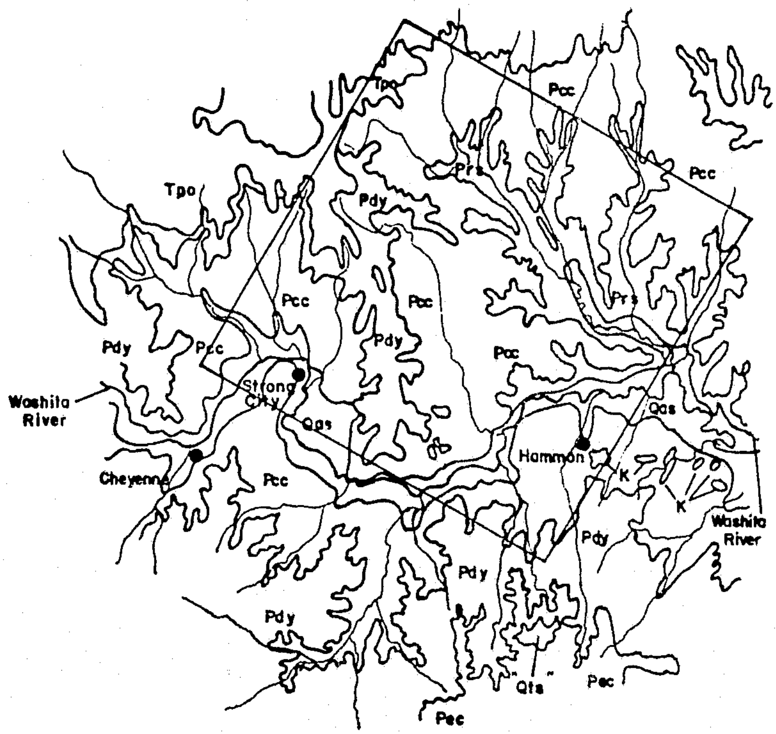


Figure 8 . Comparison of S190B lithologic interpretation with airphoto interpretation. The Ogallala formation (Tpo) is easily mapped on both images but is broken and discontinuous on S190B. The Doxey-Cloud Chief contact (D-C) is unmappable on S190B. Outcrops definitely identified as Rush Springs (Prs) from both photos are much more restricted in occurrence than indicated on the state map. Alluviated valleys (Qal) can be mapped quite well on both photos. The two sensors complement each other. Mapping of Qal near Hammond was more easily accomplished on the airphoto and a small stream was mapped in the north on S190B but not on the air photo. A textural contrast (Tx) was noted on the Skylab photo but not on the airphoto. Its origin and significance are not known. Detail is superior on the airphoto. Dotted contacts on the airphoto are obscured by clouds. Scale is 1:250,000 (reduced).



Map 5 . Geologic map of the Strong City area. Compare this map to the interpretations in figure 8 .

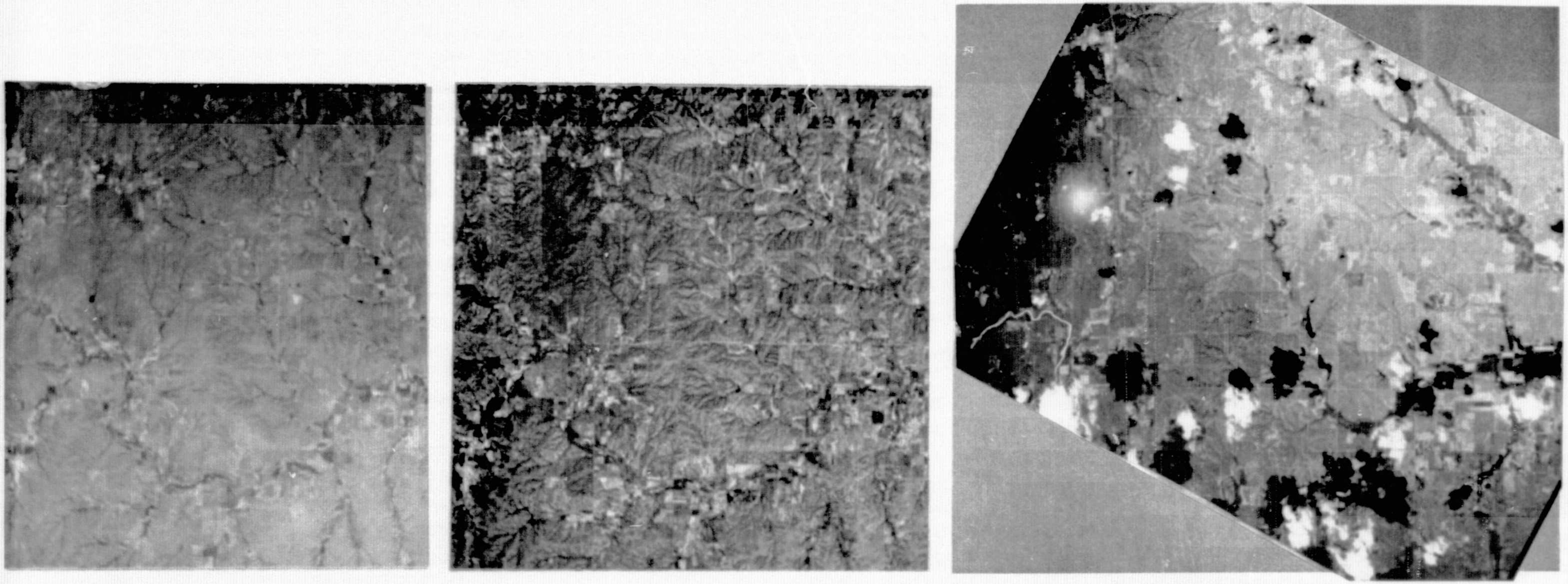


Figure 9. The Strong City area. Left to right: S190B August 1973; S190B December 1973; airphoto April 1973.-

S190B 83-046. The earlier experience plus a greater color contrast on this frame permitted mapping, with difficulty, of the Doxey-Cloud Chief contact. The important textural elements in the rocks in this area (drainage density, vegetation type and distribution, and numbers, size, color and distribution of outcrops, etc.) are too small and localized to be resolved on these space photos. However, a color contrast distinguishes Doxey from Cloud Chief on airphoto 01-113 NASA mission 236. Even the airphoto does not distinguish Rush Springs from Cloud Chief as they appear on the Oklahoma State Geologic Map. Apparently, the Rush Springs-Cloud Chief contact should be revised, with Rush Springs limited to much narrower exposures along the valley walls of Quartermaster Creek than are presently mapped. This is a judgment easily made from air photos, but not from space photos. The basal gypsum bed of the Cloud Chief formation is easily mapped on the airphoto, but only in limited areas from S190B.

The S190B photo clearly delineates the Tertiary Ogallala formation, the Quaternary and Recent deposits in stream valleys and on uplands,and in some places, the basal Cloud Chief. The Skylab photo also shows a textural contrast across a line within the Permian running northwest from Hammon, Oklahoma. This contrast is not readily apparent on the airphoto and was located only after being recognized on the space photo. It appears to have no exploratory significance and is a subtle geomorphic contrast.

Importance of an Orbital Viewpoint

The synoptic view of S190B photos combined with high resolution give them a distinct advantage over airphotos of any kind. They can be enlarged and used without the many disadvantages of mosaics. A single S190B photograph enlarged to 1:100,000 (a slightly larger scale than many high altitude photos) is only 42 inches on a side. This is too large for field work but is quite easily managed in a laboratory or office and can be cut for field work. The S190B photo covers almost 120,000 sq km. A 9 in. by 9 in. airphoto at 1:100,000 covers 520 sq km. The average ground resolved distance on S190B is about 25 m (80 ft), but objects as small as 30 ft on a side can be recognized. Narrow streams, roads and trails can be traced. Small objects that can be recognized, in context, are buildings, large trucks, trees, known outcrops, small ponds.

The S190B synoptic view in itself is an advantage in that features many kilometers apart can be related visually and

analyzed as parts of a whole. Perhaps as important is the fact that airphotos must be placed in a mosaic before equivalent studies can be performed. S190B however, is entirely free of photographic edge effects, vignetting, on individual photos, illumination and exposure differences between lines, photo to photo geometric distortions and scale differences. Contrast, color and scale are essentially constant over most of 120,000 sq km. In addition, resolution is lower on S190B photos than airphotos. Therefore, when enlargements of 1:100,000 scale are used, the need for tedious, time-consuming magnification work is eliminated. All detail is brought up to the perception ability of the unaided human eye. Air photos contain so much more detail at this scale however, that constant use can be made of magnifying apparatus.

Summary

In brief, the space photos clearly delineate lithologic units wherever there is good to moderate contrast in tone, texture or color. Although detail approaches that obtained from the airphotos, spectral and spatial resolution are lower than in airphotos, limiting the detail recorded. Important detail is lost as significant but subtle features lose their contrast because of decreased resolution or increased atmospheric interference. Information on linear features interpreted from Skylab imagery is similar to linears on airphotos in terms of numbers and azimuths of linears. Average length of Skylab linears is significantly greater than those derived from high altitude airphotos. S190B photos can replace high altitude airphoto mosaics in applications where an unobstructed regional view is more important than very high resolution. The high resolution of the airphotos and the synoptic view of the space photos complement each other.

SKYLAB - LANDSAT COMPARISON

Skylab S192 scanner images were compared to Landsat (ERTS) MSS scanner images of the same portion of the Anadarko basin (table 4). The Landsat images were made eleven days later than the Skylab images.

No simultaneous Landsat-Skylab coverage is available for our test site.

	Skylab	Landsat
Sensor	S 192	MSS
Band	(SDO) 3 (1) .50-.56μ 4 (3) .53-.61μ 5 (5) .59-.67μ 6 (7) .64-.76μ 9 (20) 1.00-1.22μ	4 .50-.60μ 4 .50-.60μ 5 .60-.70μ 6 .70-.80μ 7 .80-1.1μ
Format	5" BW Transparency	9" BW Transparency
Date	2-12-73	13-12-73
Time	1645 GMT	1638 GMT
Scale	1:790,000	1:1,000,000
Location	Duncan, Oklahoma	Duncan, Oklahoma

Table 4. Skylab scanner - Landsat comparison

Resolution and Contrast

When using S192 images, we found it necessary to continually check images and interpretations against topographic maps. The resolution and contrast are generally so low that most details are not well defined. The contrast varies from band to band and, overall, visually approximates contrast on Landsat. However, the resolution of S192 images, even though at a larger scale, is poorer than Landsat. There is considerably more electronic noise than is present in Landsat MSS data.

Because features such as towns, roads, streams and lakes are more poorly defined in S192 data, it is more difficult and time consuming to orient and locate oneself than it is on the Landsat images. It is necessary to use overlays or maps even in somewhat familiar areas. Individual points of interest (natural features) can be located within 100 meters on Landsat due both to definition of given features and to the clarity of their contexts. On S192, however, many natural features can be located only to within one half a kilometer.

Comparison of Linear Features

Interpretation of linear features on S192 scanner images is hampered by low resolution, low contrast, curved scanlines and electronic noise. More often than not, it is impossible to distinguish natural linears from sectionline roads, highways, railroads, pipelines, powerline rights of way and other non-geologic linear features. Many linears are based on straight stream valleys or alinements of a series of stream valleys or series of outcrops or topographic features. Because such features are poorly resolved, the number and certainty of linears are reduced. Continual time-consuming checks must be made against maps when interpretation fails to discriminate geologic from cultural phenomena.

Scanlines are prominent in S192 images. These lines interfere with interpretation particularly in places where the lines overlay or are parallel to geologic linears and to sun azimuth. Also the tonal contrasts between scanlines and their continuity actually mask many small features or at least make interpretation difficult and ambiguous. In addition, scanlines tend to interrupt trends transverse to the lines.

The fact that S192 scanlines are curved adds difficulties not encountered with Landsat wherein scanlines are distinct but each line maintains the same azimuth across the frame. The S192 lines are parallel to sun azimuth at one point, oblique at another and at a high angle to the sun at still other points. Scanlines vary in this same manner with respect to geologic and man-made trends, being parallel with one set of features in one spot and parallel to another set at a second point. As a result, the amount of information is lessened and interpretation is more difficult. The same and even more perplexing problems are encountered in line-straightened S192 images because a geometric distortion is introduced to the images that more than offsets the value of having straight scanlines.

The two charts in figure 10 compare the numbers and azimuths of linears 4 km or more in length as interpreted on equivalent MSS and S192 bands. In each case, the number and total length of linears are greater on Landsat. The distribution of linears is similar except for a greater number of linears between 50° and 70° on MSS band 4 (MSS-4) compared to S192 band 3 (S192-3) and a greater number at 85° to 95° on S192-9 compared to MSS-7.

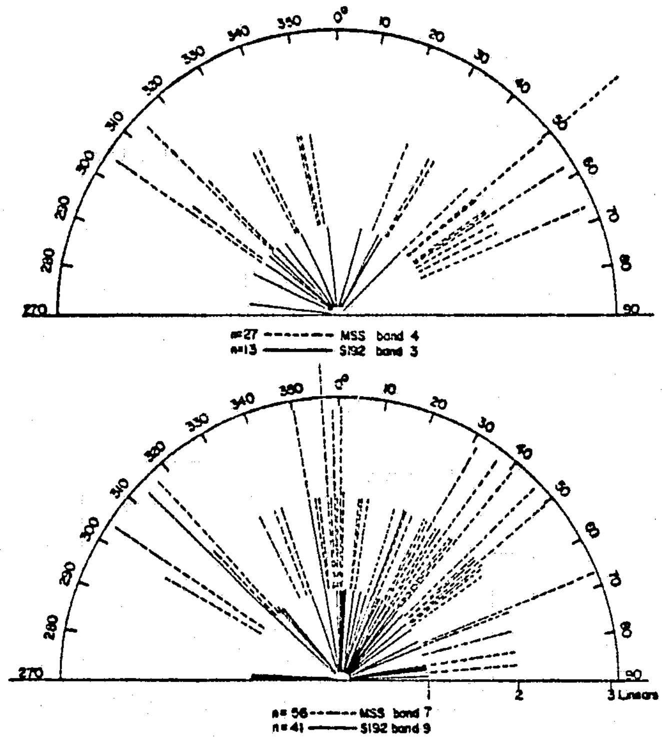


Figure 10. Comparison of linears from identical geographic areas as seen on equivalent MSS and S192 bands.

In summary, these two comparisons along with comparisons between the other MSS and S192 bands indicate there is no systematic difference in azimuth between comparable Landsat and Skylab images. The main difference is in the number and total length of linears interpreted from the two. Those S192 bands that better define topography and smaller stream segments (namely at longer wavelengths) are more similar to the MSS bands. MSS data are superior to S192 data for linears studies.

Comparison of Reflectivities

Visual comparison of Skylab S192 bands with Landsat MSS bands for reflectivities of various surfaces and for relative contrasts indicates that the S192 bands and MSS bands listed below are the most nearly comparable. In addition, S192-4 is more similar to MSS-5 than to MSS-4, contrary to indications of listed sensor responses. S192-7 is listed as most nearly matching MSS-7. In fact, S192-8 and S192-9 are also nearly identical with MSS-7, but their contrasts are lower than S192-7.

MSS band	Comparable S192 band	Other S192 also comparable
4	3	-----
5	5	4
6	6	-----
7	7	8,9

Table 5. This listing of comparable Landsat and Skylab bands is from a visual assessment of photos.

Bands 7 and 8 of S192 for December 2, 1973 were not available for comparison to the Landsat December 13 images. Comparison was made between S192-9 and MSS-7. These two bands show similar reflectivities. That is, the same features show light or dark on both bands. However, relative contrast is significantly different so that some features are in higher or lower contrast in one image compared to the other.

Bands 7, 8 and 9 of Skylab-2 on June 11, 1973 were compared to ERTS band 7 images of July 5, 1973. These comparisons showed that S192-7, 8 and 9, and MSS-7 all have similar reflectivities and similar relative contrasts. However, selected local areas within the images have higher or lower contrasts than the same areas on the other bands.

In comparing details of the S192 and MSS images, it is clear that some tonal anomalies are apparent in S192 that either do not appear in MSS images or are much more subtly expressed. For instance, an anomaly near Lindsay, Oklahoma is quite apparent on S192-3 and also appears on band 4. It is poorly defined on MSS bands 4 and 7 and is not anomalous on 5 and 6. Another anomaly, near Pooleville is easily defined on S192-6, poorly defined on 3, 4, 5 and is poorly delineated on MSS-7, not anomalous on 4, 5 and 6. In addition, the Pooleville anomaly is also apparent on S192-11 and is a highly conspicuous anomaly on band 9.

Comparison of Lithologic Features

A band by band comparison of lithologic interpretations of the Duncan area at the southeastern nose of the Anadarko Basin shows favorable comparisons between scanner images from Skylab and from Landsat. The larger scale and narrower bandwidth of the S192 scanner allow some details to be mapped that may not be mapped from the MSS of Landsat.

However, the higher contrast and better resolution of Landsat increase the ease and speed of interpretation when compared to S192.

As described in the paragraph on tonal anomalies above, there is some trade-off in visible features. For example, in figure 11 , features A and B were not interpreted from MSS-4. Area C is interpreted on MSS-4 as a stream valley eroded headward into the Hennessey shale, but this same area is mapped as an extension or outlier of the Hennessey on S192-3 and S192-4. The former interpretation more closely approximates the interpretation published on the state geologic map. The contact labelled D appears on all satellite interpretations within the Wichita group as this group is published on the state geologic map. It separates two areas of different erosion characteristics and probably marks the contact between Garber and Wellington formation equivalents. In some places the contact coincides with a sandstone labelled "t" on the state map and interpreted as basal Garber equivalent.

Compared to MSS-4:

One way in which S192 and MSS images complement each other on most bands can be seen at area E. The actual bed of the Washita River was interpreted on S192-3 and S192-4 but not on MSS-4. However, the entire alluvial valley within which the river flows is seen on MSS-4, but not on S192. These interpretations confirm the judgment that S192-3 is more similar to MSS-4 than is S192-4. The interpretation of S192-4 more closely approximates the state map than S192-3, although all three interpretations give a reasonable picture of the geology of the Duncan area. The somewhat finer detail on the S192 interpretations is due primarily to larger scale, and is not a result of resolution, which is poorer than on the MSS.

Compared to MSS-5:

Comparison of S192-5 and MSS-5 (figure 12) shows the Landsat image to be superior in most respects to the Skylab scanner. S192-5 displays details such as A and B but MSS-5 does not. Contact D more closely matches the state geologic map on S192 than on MSS. However, the overall structural, lithologic and morphologic picture is clearer on MSS-5. For instance, the Washita River valley (E) is well-mapped and continuous on MSS but is incompletely mapped on S192. Nosing in the lithologic pattern at F is quite apparent although generalized on MSS, but is not at all discernible on S192. Moreover, the locations of cities and major towns can be found on

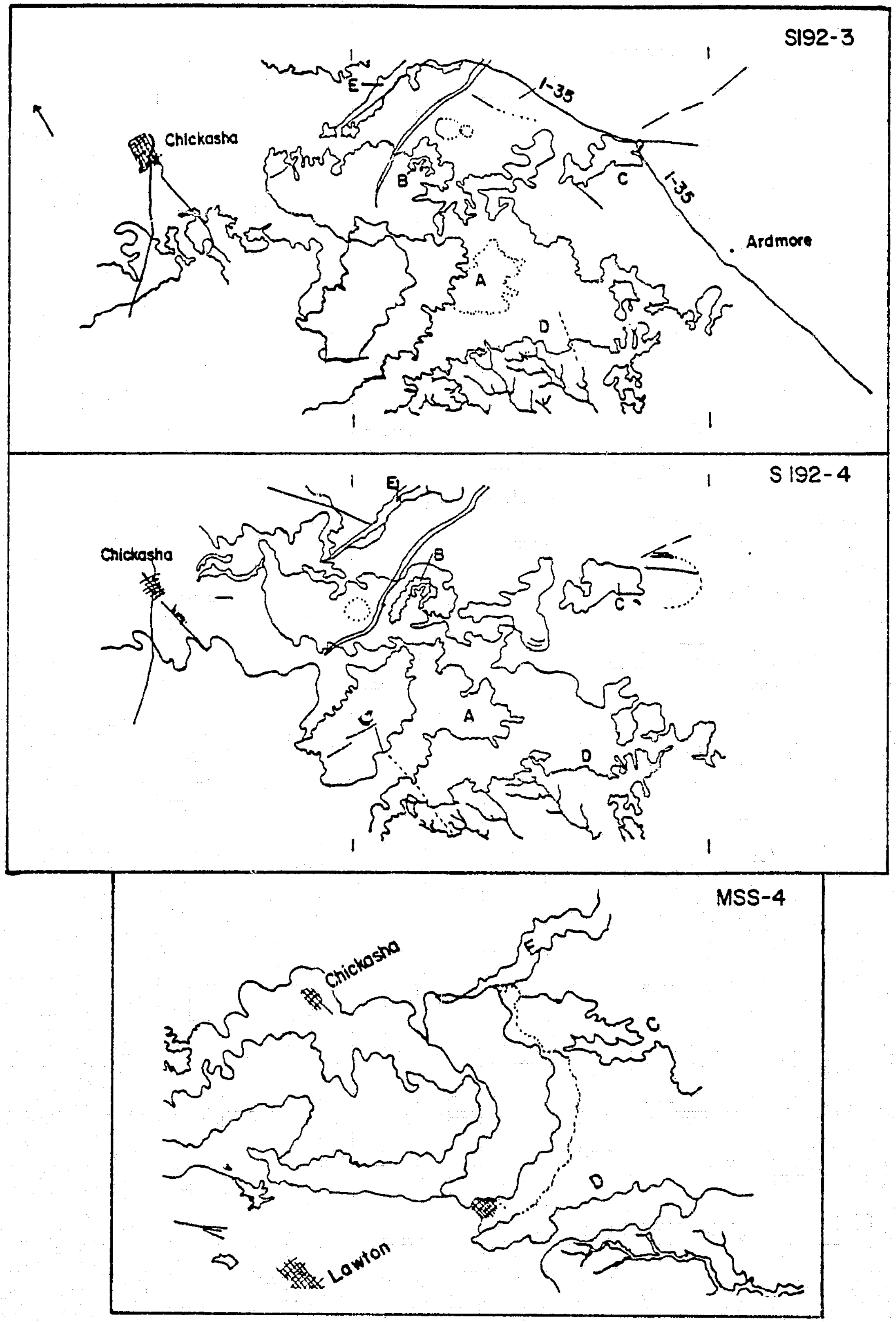


Figure 11 . Lithologic interpretation from Landsat MSS band 4 compared to Skylab S192 bands 3 and 4.

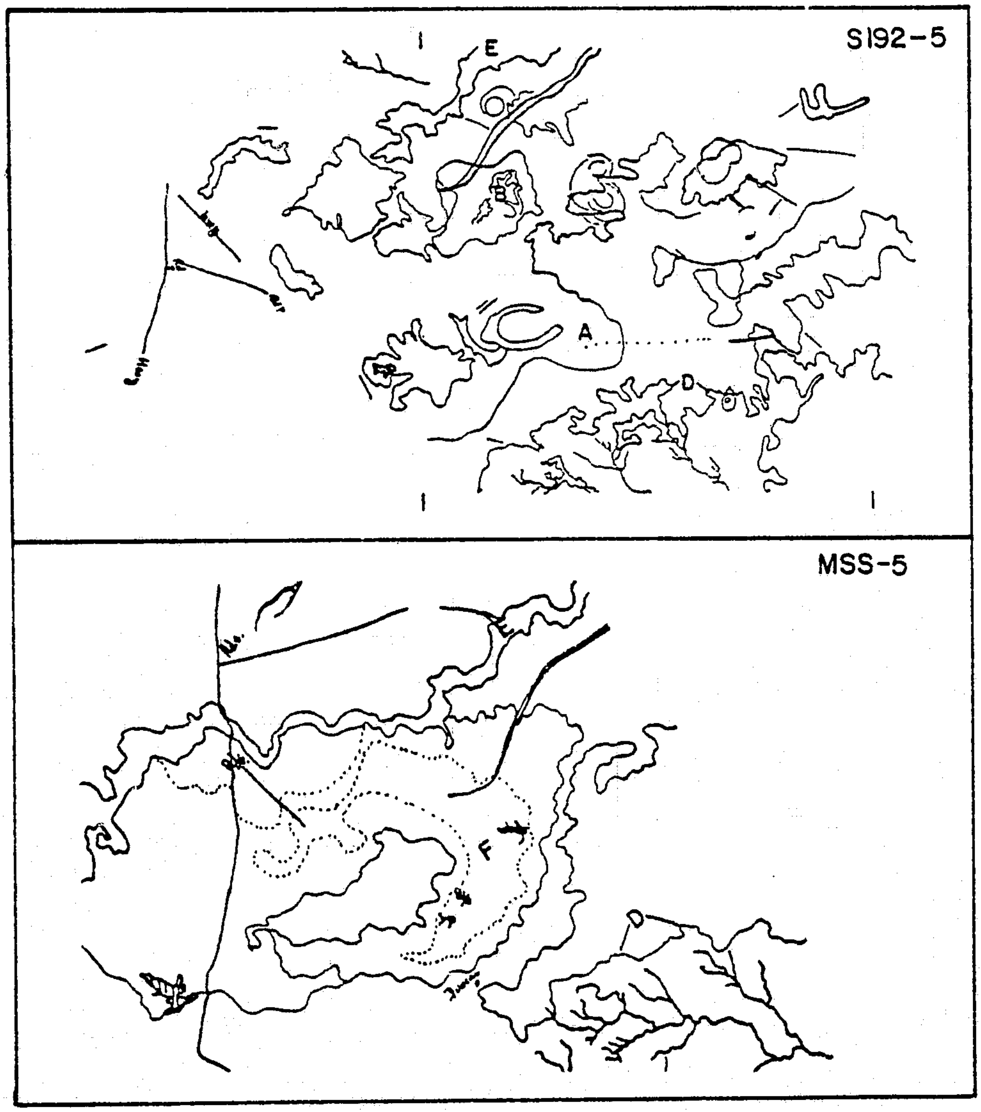


Figure 12. Lithologic interpretation from Landsat MSS band 5 compared to Skylab S192 band 5.

MSS but are not visible on S192-5.

Compared to MSS-6:

Band 6 of both scanners reveals a picture radically different from the bands discussed above (S192-3,4,5; MSS-4,5). Broad lithologic patterns are easily interpreted from those bands. However, band 6 reveals morphologic features much better than these other bands. River valleys, slopes and uplands can be seen in fair detail and such details obscure patterns dependent on regional bedrock distribution. As one example, (see figure 13) the valley of the Washita River and its tributaries (E) is plainly mapped in detail on band 6 of both scanners. In fact, almost the entire mapped area consists of interpretations of streams and topographic breaks such as D. S192-6 preserves features A and B as noted on bands 3, 4 and 5. S192-6 contains more detail than MSS-6. Note, for instance, area F. This band is best used in conjunction with another band that better resolves lithologic differences. MSS-6 is truer to published maps than is S192-6. Gross lithologic differences are somewhat clearer and most morphologic features such as stream valleys are more detailed and complete on MSS-6. Moreover, resolution and contrast are better on MSS-6. Overall, MSS-6 is preferable to S192-6.

Compared to MSS-7:

Of the three S192 bands that fall within or overlap the portion of the spectrum covered by MSS band 7, only band 9 was available for comparison to the December, 1973 Landsat images. These bands emphasize the same kinds of features that are prominent on band 6 of S192 and MSS. Morphologic features such as streams, valleys and topographic breaks are emphasized and lithologic contrasts are subdued. Riverbeds and minor stream valleys are more prominent on S192-9 than on MSS-7 although lakes and lithologic contacts are better defined on MSS-7. Contrast is a bit stronger on S192-9 than on MSS-7, but the latter is preferable for lithologic interpretation because of higher resolution and better discrimination of lithology.

MSS-7 dated July 5, 1973, was compared to S192-7, 8, 9 of June 11, 1973. Contrast seemed highest on S192-7 although careful comparison shows that contrast may be higher or lower on one band or another for given features. Overall, all these bands produce similar lithologic interpretations. MSS-7 is preferred because of higher resolution of features. Roads, lakes, fields, major stream valleys are all much better defined on Landsat than on Skylab.

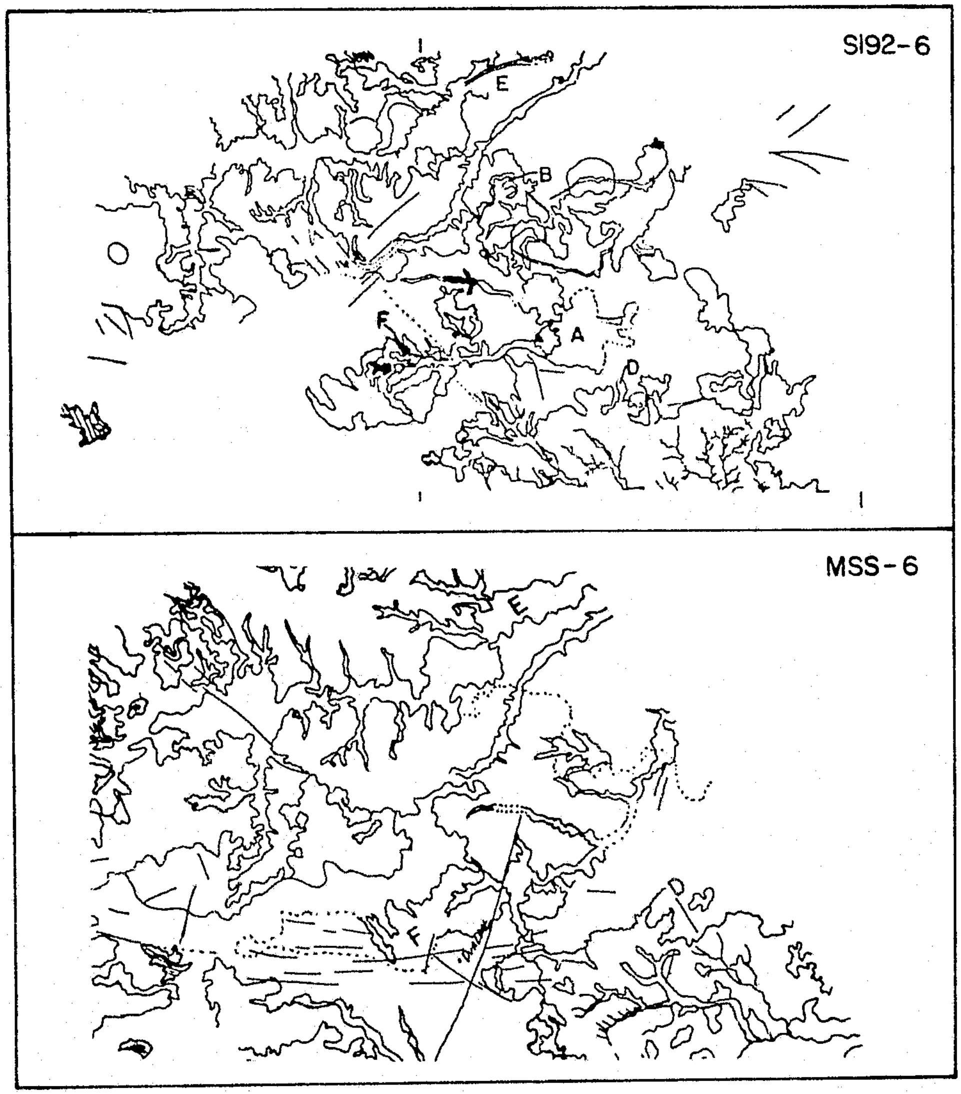
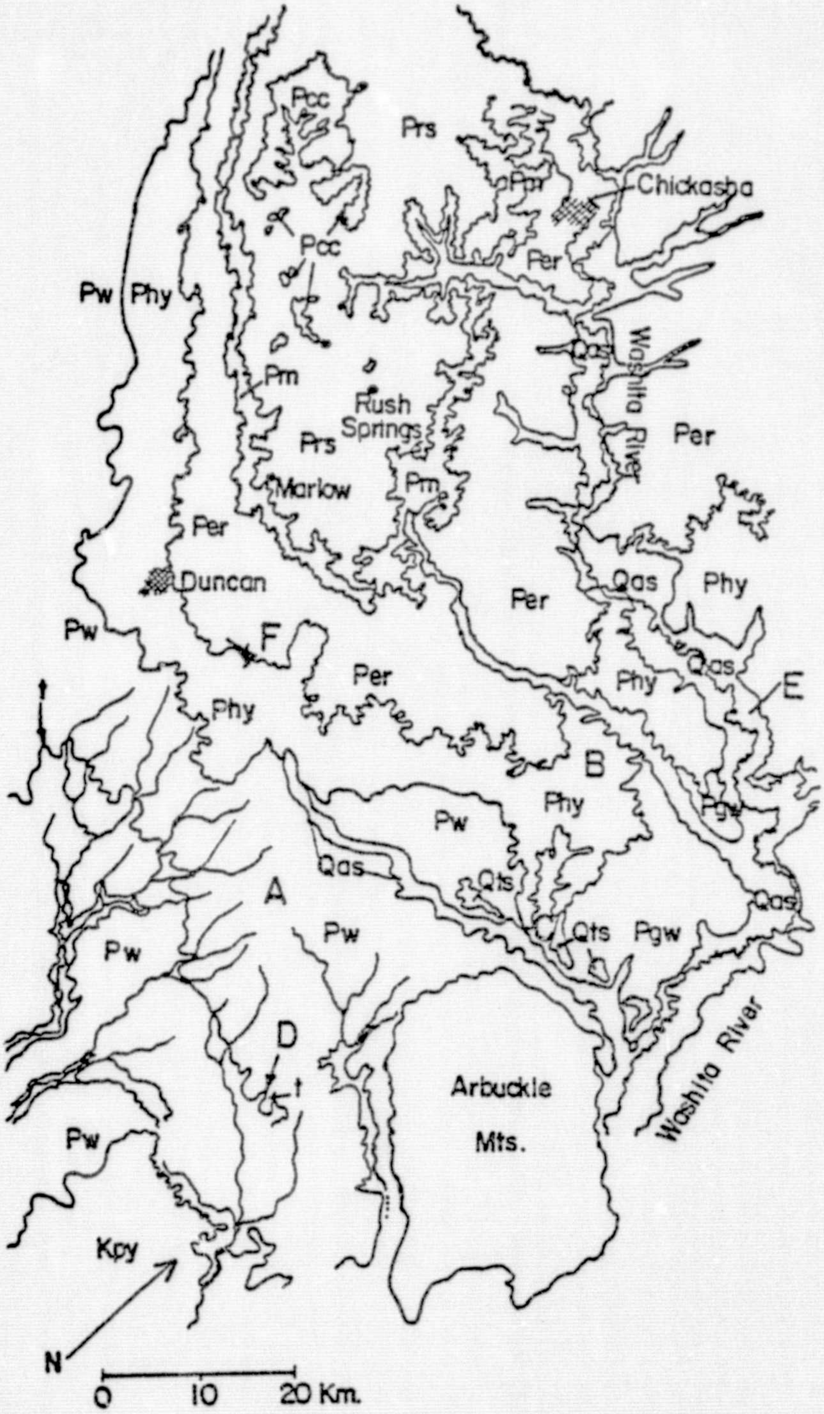


Figure 13 . Lithologic interpretation from Landsat MSS band 6 compared to Skylab S192 band 6.



Map 6 . Sites A through F are referred to in text and interpreted in figures 11 , 12 and 13 .

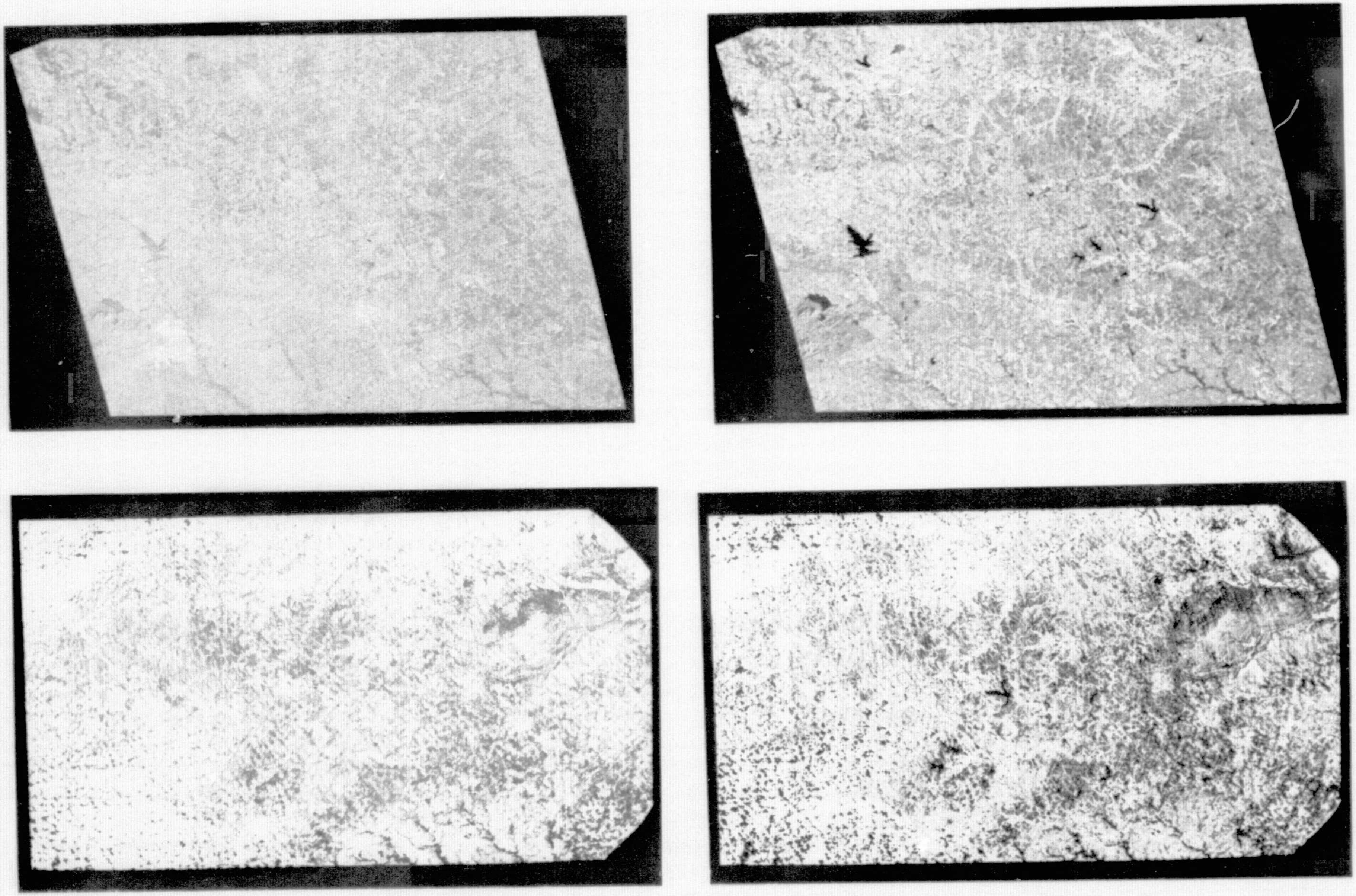


Figure 14. Landsat images (top) compared to similar Skylab images.
Left: MSS-4 and S192-3. Right: MSS-7 and S192-9.

LANDSAT (MSS)	SKYLAB (S192)	PREFERRED	COMMENTS
4	3	MSS	S192-3 adequate substitute
4	4	MSS	S192-4 " "
5	5	MSS	MSS-5 Definitely superior
6	6	MSS	S192-6 adequate substitute
7	9	MSS	S192-9 " "

Table 6 . Skylab S192 and ERTS MSS compared for geologic interpretation.

Summary

S192 data have the distinct advantages of multiple, narrowly defined bands with an extended look well beyond the visible into the infrared. The Landsat (ERTS) MSS images are superior in terms of resolution or definition of features, offer less difficulty with scanlines and allow much greater ease of interpretation and economy of time than the S192 images.

IV. GEOLOGICAL STUDIES

LINEARS

Skylab images reinforce the results of our earlier ERTS studies and refine many details. Faults can be precisely located and their sense of displacement sometimes described. The orbital imagery forces us to take a fresh look at older data and to compile new information. Figure 15 summarizes the azimuths of linears interpreted from S190A and B photographs and S192 scanner images.

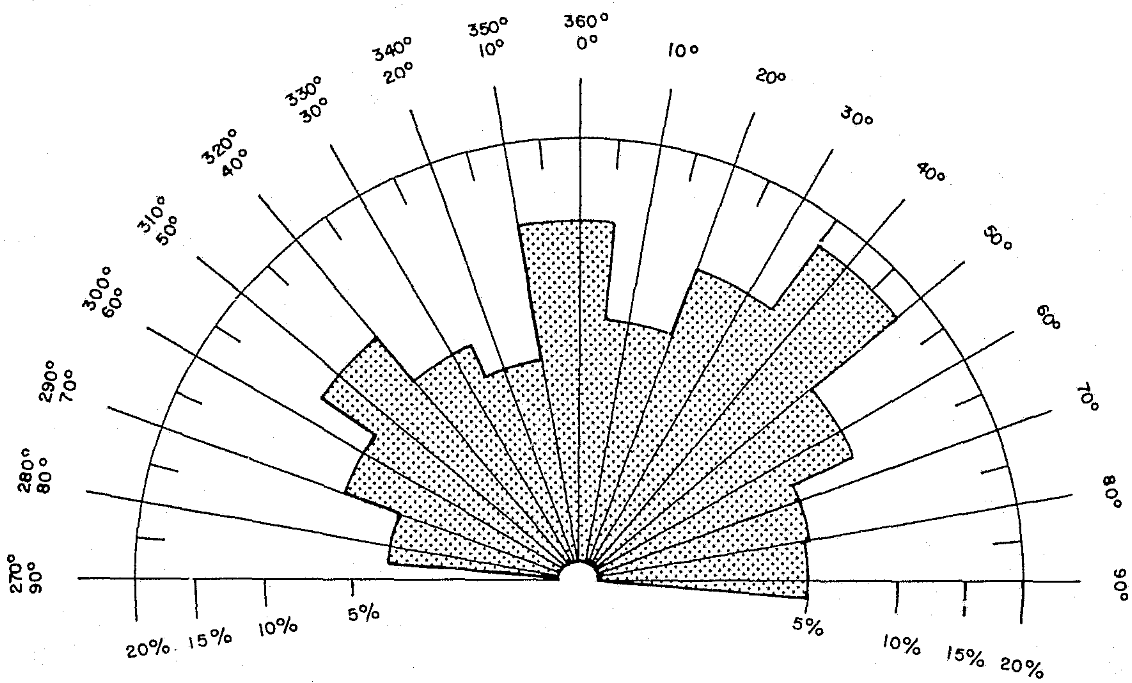


Figure 15. Equal-area semi-circular histogram of orientations of Skylab linears in the Anadarko Basin. Total number of linears = 1123. These orientations are essentially the same as those determined in Collins _et al_. (1974). Refer to figure 16 for a direct comparison of this study with Collins _et al_. 1974.

A preliminary test of the validity of Skylab linears was made using a single frame (S190B, 90-144) at 1:250,000. The linears were compared to faults interpreted from four lines of reconaissance seismic data. Orientations of faults are difficult to determine from such data. The linears were also compared to proprietary subsurface structure maps based on drilled stratigraphic units.

Faults	Linears	
	Match	No Match
Seismic	21	11
Drilled	4	3

Table 7 . We compared Skylab linears to 39 known subsurface faults. Twenty-one faults interpreted from seismic data are marked by linears. Fifteen linears closely approximate the seismic trends. Six others are oriented $20° \leq 45°$ to the seismic faults. Only seven drilled faults occur in the area. Four are marked exactly by Skylab linears.

Skylab linears showed good agreements with the mapped subsurface faults (table 7). However, the linears cannot be said to be diagnostic of faulting, particularly in view of the fact that there are hundreds of other linears. The linears associated with faults are mostly parallel either with major directions of faulting and fracturing or with regional linear trends, and to this extent are distinguishable from many others.

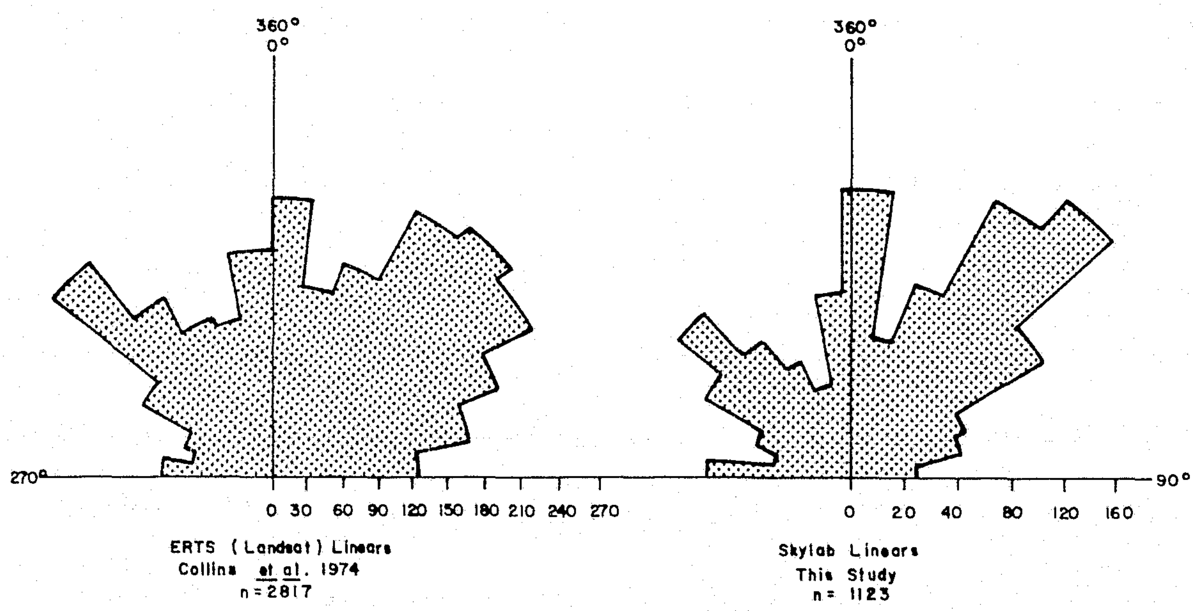


Figure 16 . Rose diagrams comparing the orientations of Landsat linears with Skylab linears. Radii are directly proportional to the number of linears in each 10° class.

Figure 16 shows that the linear trends visible on Skylab match those seen on Landsat. The small discrepancies between the two plots are probably accounted for by the fact that time of year, and therefore sun angles and azimuths, was significantly different on our Skylab images (Appendix C) when compared to ERTS appendix A (Collins, 1974, p.126). This comparison reinforces our confidence in the geologic basis of the linears. Furthermore, it indicates that sensor type generally has a minimal influence on the pattern of visible linears and that sun illumination conditions have a surprisingly small effect for this region of low dip and subdued topography.

The relationship between Skylab linear trends and Anadarko Basin tectonics is not clear. It is clear however, that they coincide with major joint directions. The N80W joint direction is more prominent than shown in our ERTS linears illustration (Collins, 1975, figure 9) but Skylab shows this trend somewhat better (figure 16).

The Skylab interpretations emphasized the validity of the north-south peak discussed in our ERTS study (Collins, 1974, p.65) and shown here in figure 16. Also, our field work continued to show that although north-trending joints have a lower frequency than other major joint directions, their surface expression is more profound. North-south joints are usually more continuous, more distinct and certainly have greater topographic expression than most others, thereby having greater expression on space acquired images.

The high resolution of Skylab photos enabled us to specifically interpret several linears as faults. Some of these linears were not even noted on Landsat. Others were very generalized and were simply treated as major trends.

Two faults were mapped precisely from S190B in T.7N.-R.24W., Greer County, Oklahoma (figure 17). They appear on the state geologic map. See map 3 . Field checks showed the faults are marked by breccia, patches of bleached redbeds, selenite veins (recrystallized gypsum occupying joints), many small folds, and many small intraformational imbricate thrust faults. Skylab indicates a third fault trending northeast and truncating the two mapped faults. This linear has the same characteristics on the image as the faults. A field check did not precisely define this fault. However, its existence seems verified by the few, poor outcrops all of which had some discoloration, local dips of 2° to 5° (regional dips are <1°), and were shot through with selenite veins.

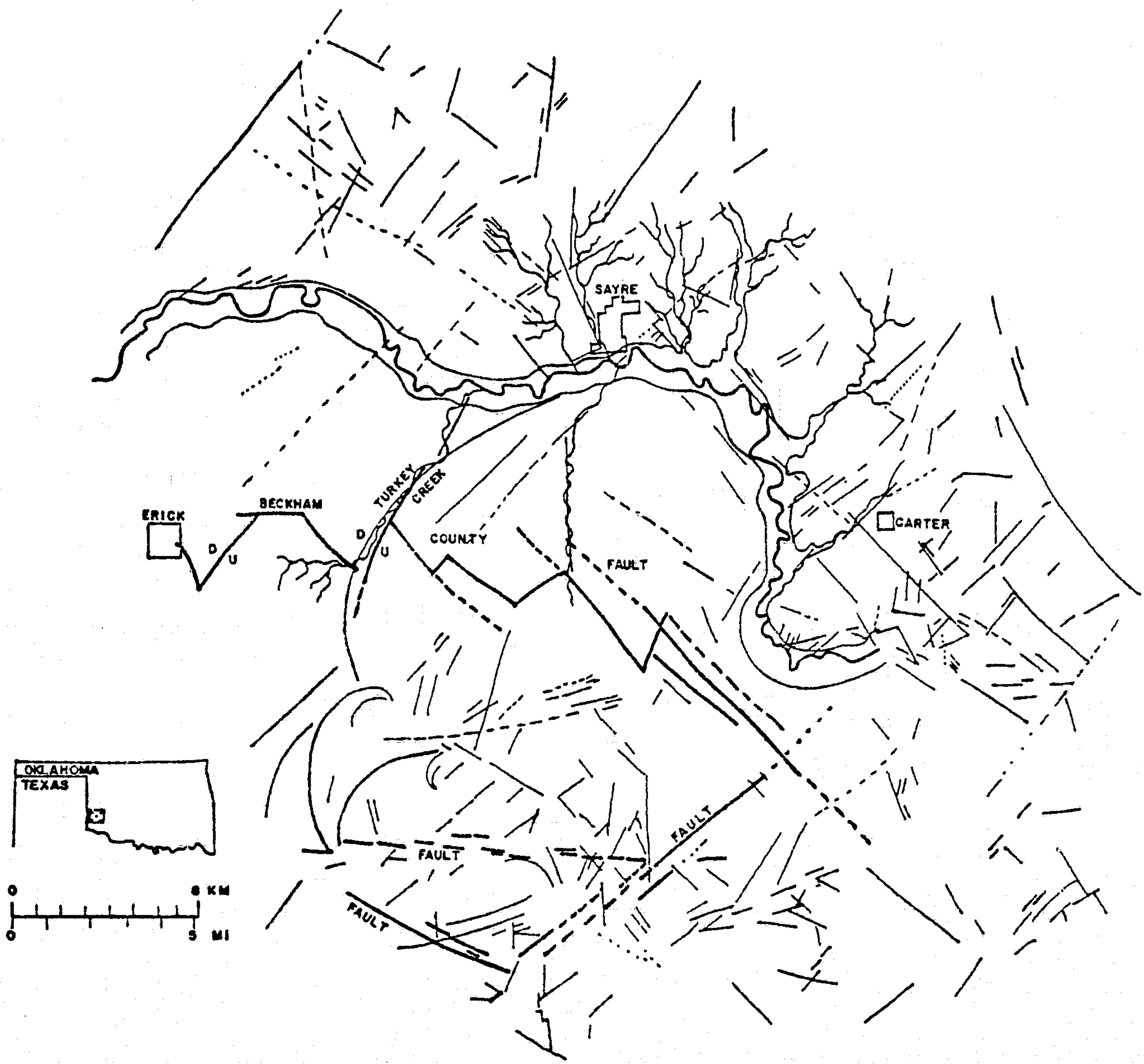


Figure 17 Two surface faults southeast of Erick, Oklahoma were mapped from Skylab 190B prints. They are shown herein on map 3 . On Skylab images these two faults appear to be truncated by a third fault trending N50E. A field check confirmed the existence of this fault. Skylab photos for the first time reveal a complex surface expression of the Beckham County Fault. A field check confirmed the existence of surface faulting along southern Turkey Creek.

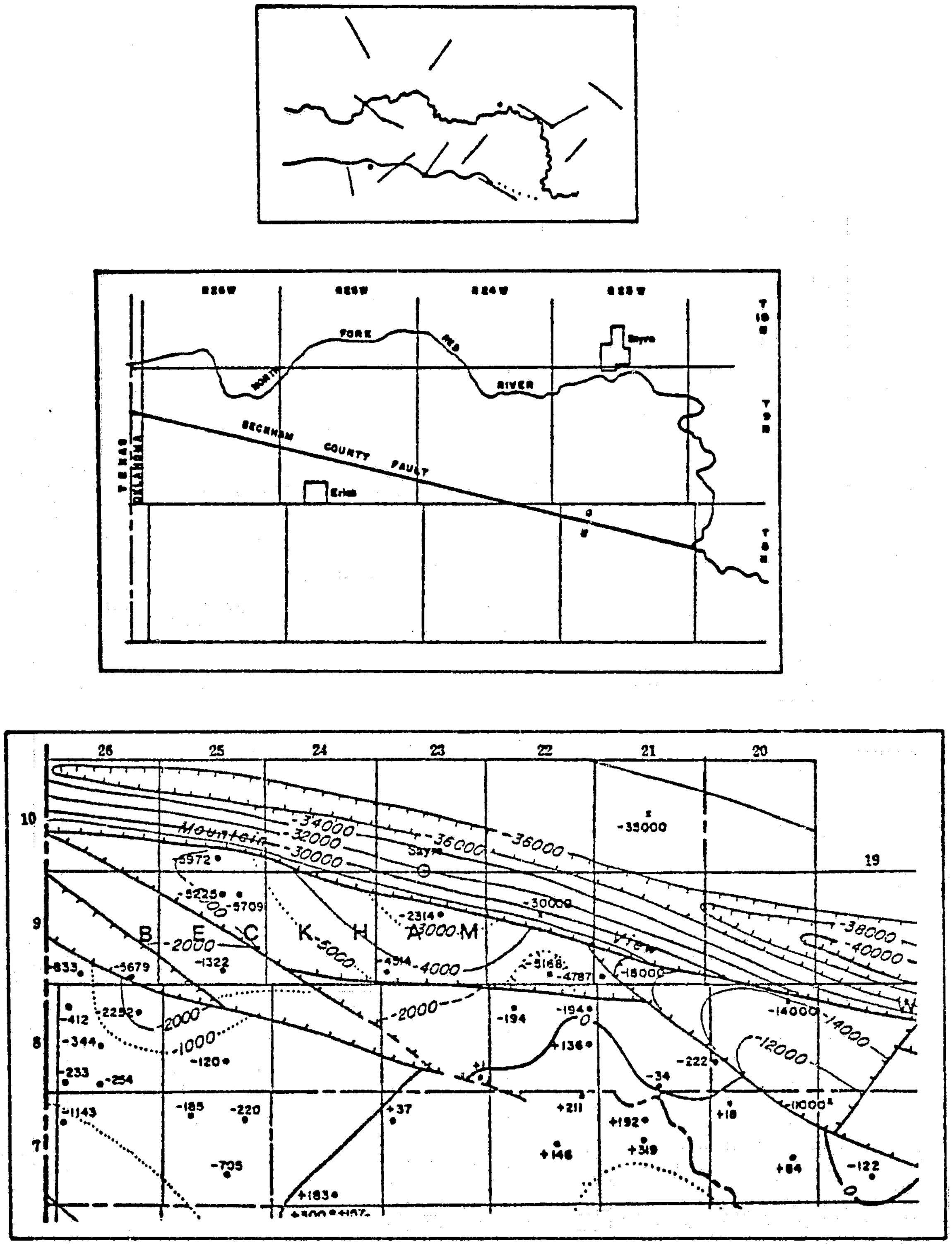


Figure 18. Three interpretations of faults in Beckham County, Oklahoma. Top: The Beckham County Fault as seen on Landsat (1257-16473). Middle: Beckham County Fault according to Gouin in Oil and Gas in Oklahoma (1928). Bottom: Interpretation of basement faults by Ham et al. (1964). Contours are on top of basement rocks. Compare these interpretations to Skylab S190B interpretation in figure 17.

The Beckham County fault (figure 17) is clearly distinguishable on Landsat. S190B photos seem to show that this fault is offset by a series of normal faults, giving it a jagged appearance that is seen as a wavy boundary on Landsat. Although the Beckham County Fault was long ago defined from water well data (Oil and Gas in Oklahoma, 1928) and is represented as a basement fault (Ham, 1964, Plate II), apparently it has not been studed in detail at the surface. Refer to figure 18. Skylab shows soil color contrasts from east to west along Turkey Creek in T.8N. and T.9N.-R.24W. The contrast was borne out by field checks that showed red residual soils on the east where bedrock is apparently close to the surface and gray on the west where the soils are deeper and composed of alluvial and eolian clays and sands. A single good outcrop along this trend exposes discolored, disturbed beds with dips up to 20°. Strata are cut by selenite veins.

The Mountain View Fault, a major regional fault of the Wichita Mountain system was undetected on Landsat. Portions of it show quite well on S190A and B. It is a zone of many small linears, topographic breaks and alinements, and soil color changes, all readily apparent on Skylab.

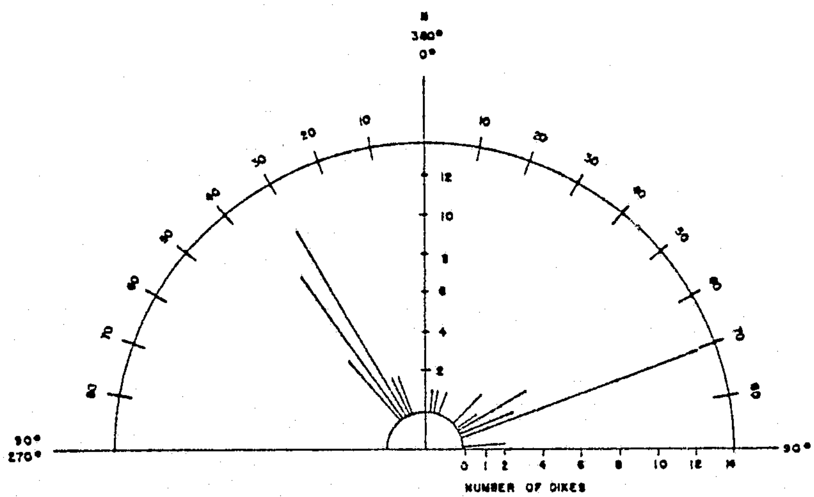


Figure 19. Circular diagram indicating the number and azimuths of sandstone dikes located in central and northwestern Anadarko Basin.

Field work for our ERTS and Skylab studies brought to our attention many sandstone dikes, apparently of tectonic origin. We have not had occasion to study the dikes carefully. However, there is no direct evidence of them on Skylab. Their frequency and direction (figure 19) do not fit exactly either with remotely sensed linears or with compiled joint data. The significant point here is that

these dikes have apparently been overlooked or dismissed out of hand in the past. Satellite data have shown us areas or features we thought needed field checking. This new look and stimulation have brought to our attention features such as the sandstone dikes, selenite veins, zones of disturbed bedding and brecciation. Hopefully these features eventually will lead us to a better understanding of the age and mechanics of tectonism in the Anadarko Basin.

ANOMALIES

In General

Geomorphic anomalies are the most common type of anomaly on Anadarko Basin images. Most of these, in turn, are drainage anomalies or patterns. The most common anomalies in our earlier ERTS study (Collins, 1974) were subcircular and arcuate, most of which have proved to be drainage patterns, combinations of geologic features and fortuitous arrangements of non-geologic features. Skylab's high resolution reduces ambiguity, thereby eliminating many fortuitous (non-geologic) anomalies and increasing certainty about the nature of the remaining anomalies. Figure 20 shows the Skylab anomalies in the central Anadarko Basin.

In certain areas, where the surface is maturely dissected and contrast is relatively high, drainage patterns can produce an abundance of apparent anomalies such that they are generally meaningless. Easternmost Roger Mills, northeastern Custer and southernmost Dewey Counties (R.17W. to R.21W. and T.14N. to T.16N.) in particular showed an overabundance of circular, arcuate and drainage anomalies. In such areas, the high resolution of Skylab photos presents difficulties for interpretation. The great number of visible details actually creates ambiguities and false anomalies. Only by taking a second or third, close look and by careful checks against airphotos can the more substantial anomalies be determined. In these areas of dense dendritic drainage networks, detailed drainage and fracture analysis are much more fruitful than reconnaissance interpretation for broader anomalies.

The Reydon, Oklahoma area is another site of multiple anomalies. These anomalies all overlap and cover an area of about one township just west and north-west of Reydon. All the anomalies seem to have a sound basis in real surface features and are seen on different photos. There are also several Landsat anomalies at Reydon. This is a site of current high interest for gas exploration.

The area just west of Reydon is now developed as a gas field. No strong subsurface structures have yet been mapped northwest of town that can be related to the surface features. However, these overlapping anomalies may give a good indication that the field can be extended northward if the anomalies can be tied to other geologic conditions. It is possible that the Reydon site fortuitously contains many features that, when combined, merely seem to be real and anomalous. Closer study seems to indicate otherwise.

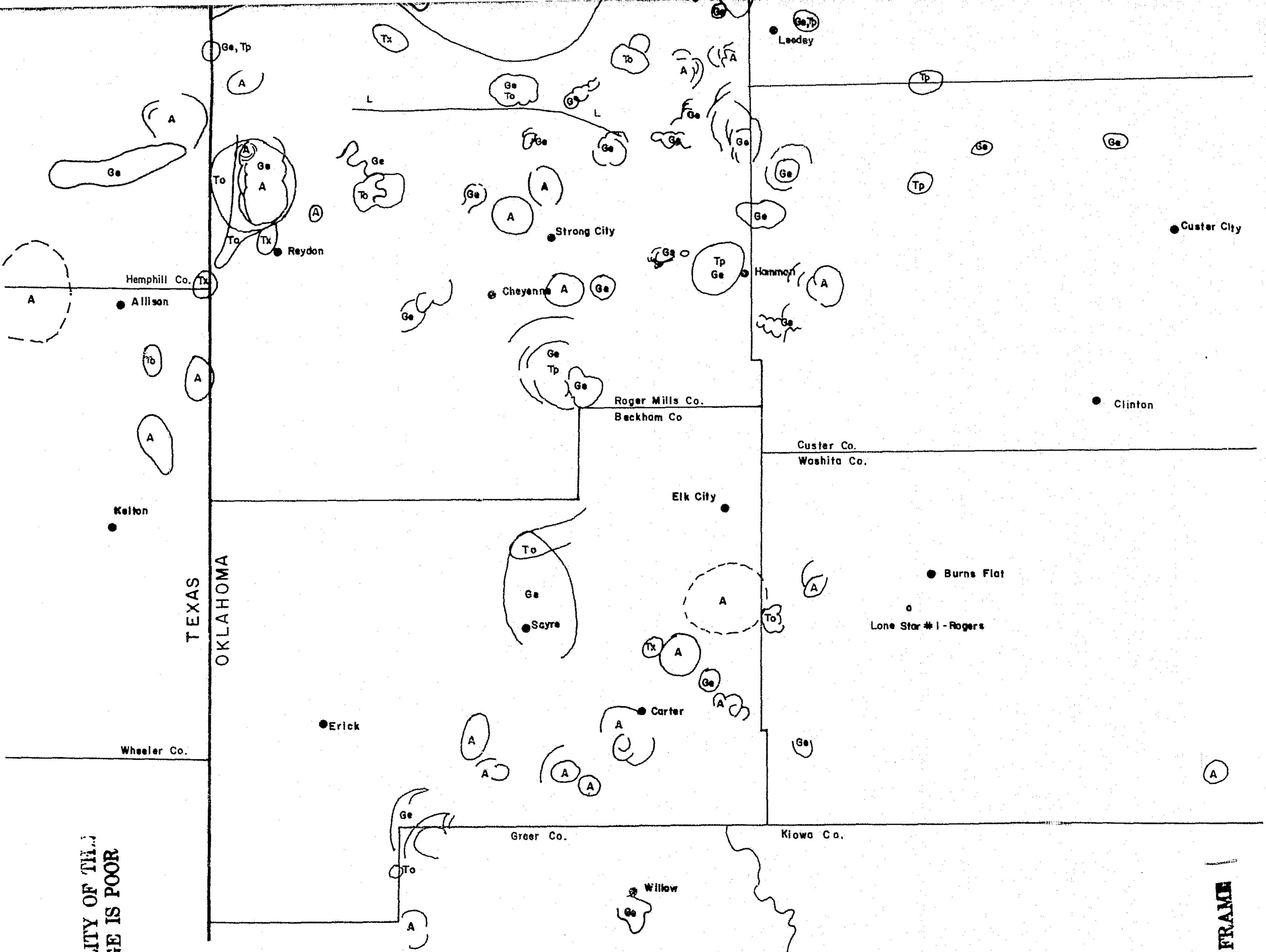


Figure 20 . Skylab anomalies of the central Anadarko Basin. A = Arcuate or Circular; Ge = Geomorphic; L = Linear tonal anomaly; To = Tonal; Tp = Topographic; Tx = Textural.

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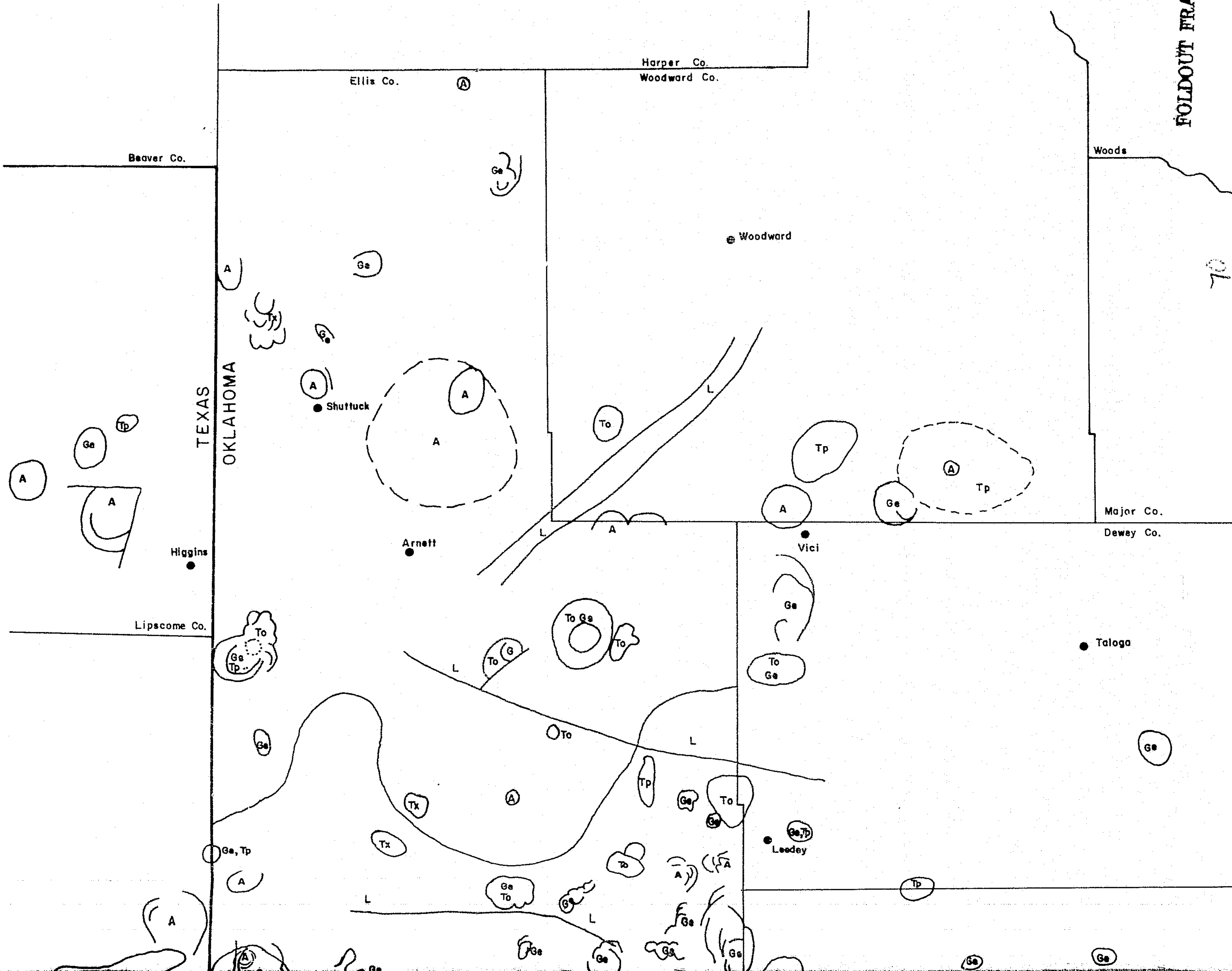


Classification and Analysis

We compared Skylab anomalies with hydrocarbon fields and structures known from seismic and structural information and with anomalies reported in our ERTS study (table 8). There are 107 anomalies in the central and deepest portion of the basin, the only portion with several complete image sets. Anomalies were typed as arcuate (includes subcircular and arcuate), geomorphic, textural, tonal, topographic and linear zones. There is much less information available on the central basin than on all other areas mainly because the deepest parts are untested by the drill. Altogether 48 anomalies coincide with known structures or producing fields, 59 do not. We emphasize, however, that 29 anomalies occur within the untested portion of the basin. After all anomalies are tested, the ratio of 48:59 should change significantly to the left.

Anomaly Type	Total	Coincide with (A) O/G Field	(B) Dry Struc.	(C) No Features	ratio A+B:C	Circular only (arcuate type eliminated)
Geomorphic	39	8	6	25	14:25	10:13
Arcuate - Subcircular	31	10	6	15	16:15	10:8
Tonal	19	8	2	9	10:9	-----
Topographic	9	4	0	5	4:5	-----
Textural	6	1	2	3	3:3	-----
Linear Zones	3	1	1	1	2:1	-----

Table 8 . Comparison of Skylab anomalies of the central Anadarko Basin with geologic features of interest for exploration. This sample indicates that completely closed anomalies are most reliable for picking prospects. In general, they are more vaguely defined than the arcuate types. Many of these anomalies occur in the central basin which is essentially unexplored by the drill.

Arcuate (and/or near-circular) and tonal anomalies have the highest correlation with known features of exploration interest. There are 31 arcuate anomalies. Sixteen match known features. It should also be noted that 14 of the total of 31 occur in untested areas of the basin. Only two of the fourteen match inferred structures.

Ten tonal anomalies correlate with significant features. Most of these anomalies are associated with stratigraphic fields. Nine tonal anomalies are unrelated to any features. The causes of tonal anomalies are generally obscure, but most seem to be associated with soils and vegetation in stream valleys and at stream junctions. Others relate to exposures of sandy soils on flat uplands or vegetation on such lands.

Our geomorphic and arcuate classes can both be subdivided into geometric classes roughly described as arcuate and circular. The arcuate types were found to consist mostly of drainage patterns. Circular or subcircular anomalies usually consist of two or more features such as an arcuate topographic break continuous with an anomalous arc in a stream valley or with an arcuate tonal linear.

Upon reclassifying geomorphic and arcuate anomalies by their geometry we found the greatest correlation of anomalies to significant features is within the vaguely circular type. Refer to the right-hand column of table 8 . Twenty of 41 circular anomalies coincide with known features and only ten of 29 arcuate anomalies do so. The arcuate types on Skylab photos seem to be related more to fortuitous stream patterns than to underlying geologic structures. In fact, our ERTS study indicated the opposite. Arcuate anomalies outlined such major features as Mobeetie, Elk City (Collins, 1974, p.98, 102) and the SW Buffalo to NE Selman area (Collins, 1975a, illus. 39).

Compared to Landsat

Most Skylab anomalies do not coincide with anomalies derived earlier during our ERTS study. This lack of correspondence is probably the result of complex interaction of several factors. First, the higher resolution of Skylab photos has several effects. Most features are more clearly defined than on Landsat images and interpretations are less ambiguous thereby eliminating some anomalies. This is especially true of the numerous circular (closed) anomalies from ERTS. Other anomalies are simply lost on Skylab amid the "noise" of fine detail. Second, "hazy" anomalies as a class are lost on Skylab. Third, we simply did not have the same frequent coverage under a variety of conditions that we had for ERTS. Seasons, time of day and sun angles are significantly different between the Skylab and the ERTS passes. Fourth, only two of the 107 Skylab anomalies considered here were derived uniquely from scanner data. All our ERTS anomalies, of course, are from a scanner. Moreover, the low resolution and high noise content of the S192 scanner greatly reduced usefulness of the images. Fifth, the Skylab data, including S192 scanner data, are all very different from Landsat data and thus emphasize certain natural features and obscure others that Landsat does not.

Skylab type	Matching ERTS type	Total
Geomorphic	Geomorphic	4
Arcuate	Arcuate	5
Geomorphic	Arcuate	6
Arc., Tonal, Topo.	Geo., Arc., Hazy	6
Various (5)	Hazy (2)	(5)
	Total	26

Table 9 . Twenty-six of 107 Skylab anomalies match ERTS (Landsat) anomalies as shown in Collins *et al*. (1974). Improved resolution permitted redefinition of six arcuate anomalies (denoted as "closed" in Collins, 1974) as definite geomorphic anomalies.

Twenty-one Skylab anomalies coincide with our ERTS anomalies and five others fall within two larger "hazy" anomalies (table 9). In general, Skylab and ERTS anomalies match type for type. The main difference is that six anomalies earlier classed as arcuate (closed) were defined as geomorphic when more detail was encountered on Skylab images. The coincidences have increased our confidence in these particular anomalies. In fact, some have been successfully drilled by other companies since our ERTS project began. This is, once again, a demonstration of the utility and value of multispectral-multisensor data. Many anomalies can be located by Skylab that are undetectable from Landsat and *vice versa*. Some anomalies can be verified, reinforced, refined, or eliminated by multiple techniques and tools. Where both Skylab and Landsat data are available both should be used.

Anomalies of Individual Interest

Turkey Creek:

The anomaly at Turkey Creek in T.18N.-R.22W., Ellis County, Oklahoma has been of particular interest since early in our ERTS study. This location was marked as an extension of a large hazy anomaly (Collins, 1974, p.93). On Skylab (S192, S190A,B) it appears as a tonal and topographic bull's-eye similar to the Buffalo Wallow anomaly (Collins, 1974, p.102). Interpretation on S190B at 1:100,000 (refer to figure 21) shows deflected and partly radial drainage around a topographic high. Within the anomaly there is a slight difference in the density of vegetation with no apparent soil color anomaly. The wells within the

anomaly all produce from Morrow (lower Pennsylvanian) sands. There is no appreciable local subsurface structure, although this field is associated with a slight regional anticlinal nose. The three central wells had an average calculated absolute open flow (CAOF) potential of about 6300 thousand cubic feet of gas per day (Mcfgpd). The westernmost well on the periphery of the anomaly had a CAOF of only 1200 Mcfgpd. If the anomaly closely defines probable production, we might expect the two current locations to be producers with a chance of fracture porosity in the northeast location. These wells were all drilled after the start of our ERTS study, indicating the potential of carefully selected anomalies.

In some respects the Turkey Creek anomaly is similar to several other significant anomalies. It has a central bright area within a surrounding darker area just as Buffalo Wallow on Landsat. It is a topographic high surrounded by anomalous drainage similar to Aledo and Leedey as seen on Skylab.

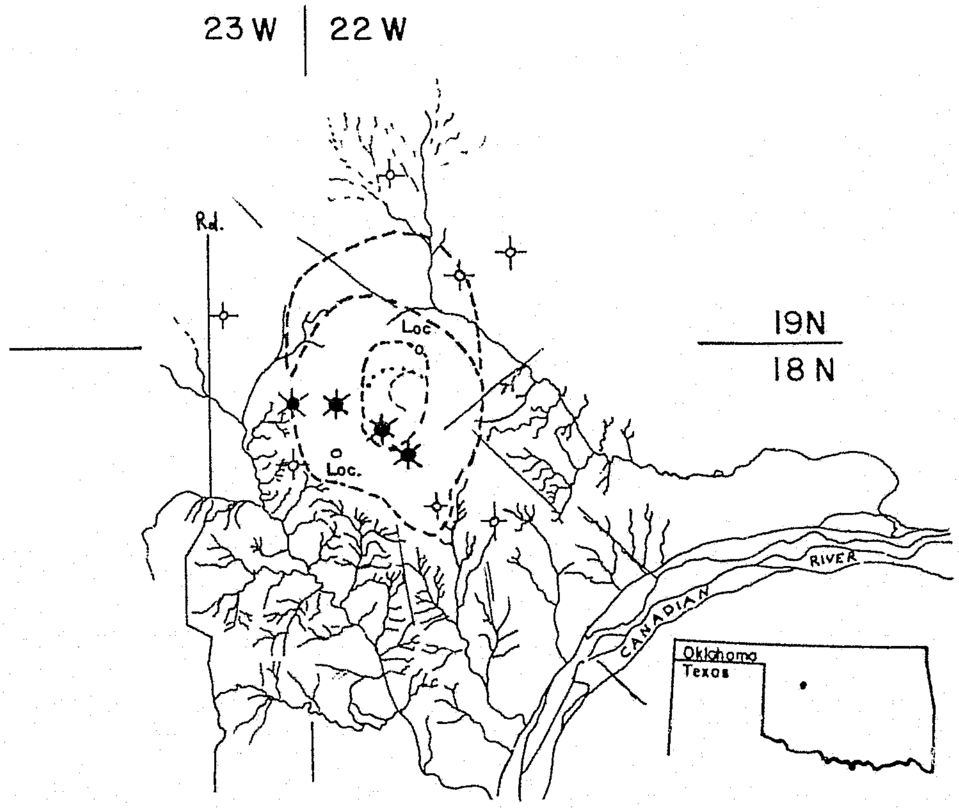


Figure 21 . The Turkey Creek anomaly as interpreted from SL-4, 90-144 Earth Terrain Camera at scale of 1:250,000.

Leedey:

Part of the Leedey anomaly is spurious. The central part is a dark vegetation "anomaly" that seems to be simply an uncultivated area, a fact not apparent on Landsat or S192 scanner imagery. The light soils do not show through on this pastureland as well as they do in cultivated areas. On the other hand, this is a rolling upland in an otherwise well-dissected, almost badlands area. The town of Leedey occupies another such comparative flatland. The drainage is not in a definite radial pattern although in detail at valley heads it probably approaches a radial pattern. The divide between Canadian River drainage and Washita River drainage to the south runs anomalously east-west at this location. Refer to figure 22. At present, the center of a small structure is interpreted to underly the 1970 discovery gas well. This well had an initial production (IP) of 17 million cubic feet of gas per day with a CAOF of 56 million. It produces from the Hunton limestone of Devonian age. Total depth is 16,892 ft. In June of this year (1975) a small oil well

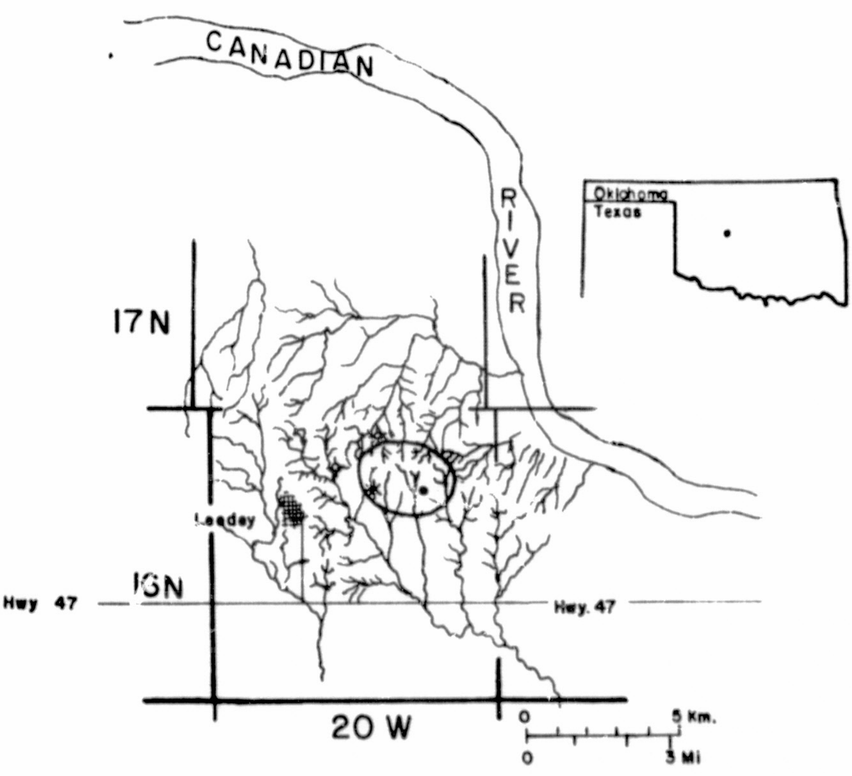


Figure 22. The Leedey anomaly coincides with a structure centered below the gas well. The anomaly as outlined on Skylab photos encloses both the 1970 gas well and the oil well, completed in 1975.

(36 BOPD) was completed in upper Pennsylvanian Tonkawa sand at 8245-8307 ft. The Hunton was not tested. Both wells are marked in figure 22.

This anomaly is within the area of dense dissection, described above, where there are many apparently spurious circular and arcuate anomalies. Only careful drainage analysis will sort prospects such as Leedey from spurious anomalies. Drainage analysis can be done from S190B photos, but is best done on good aerial photographs.

Elk City:

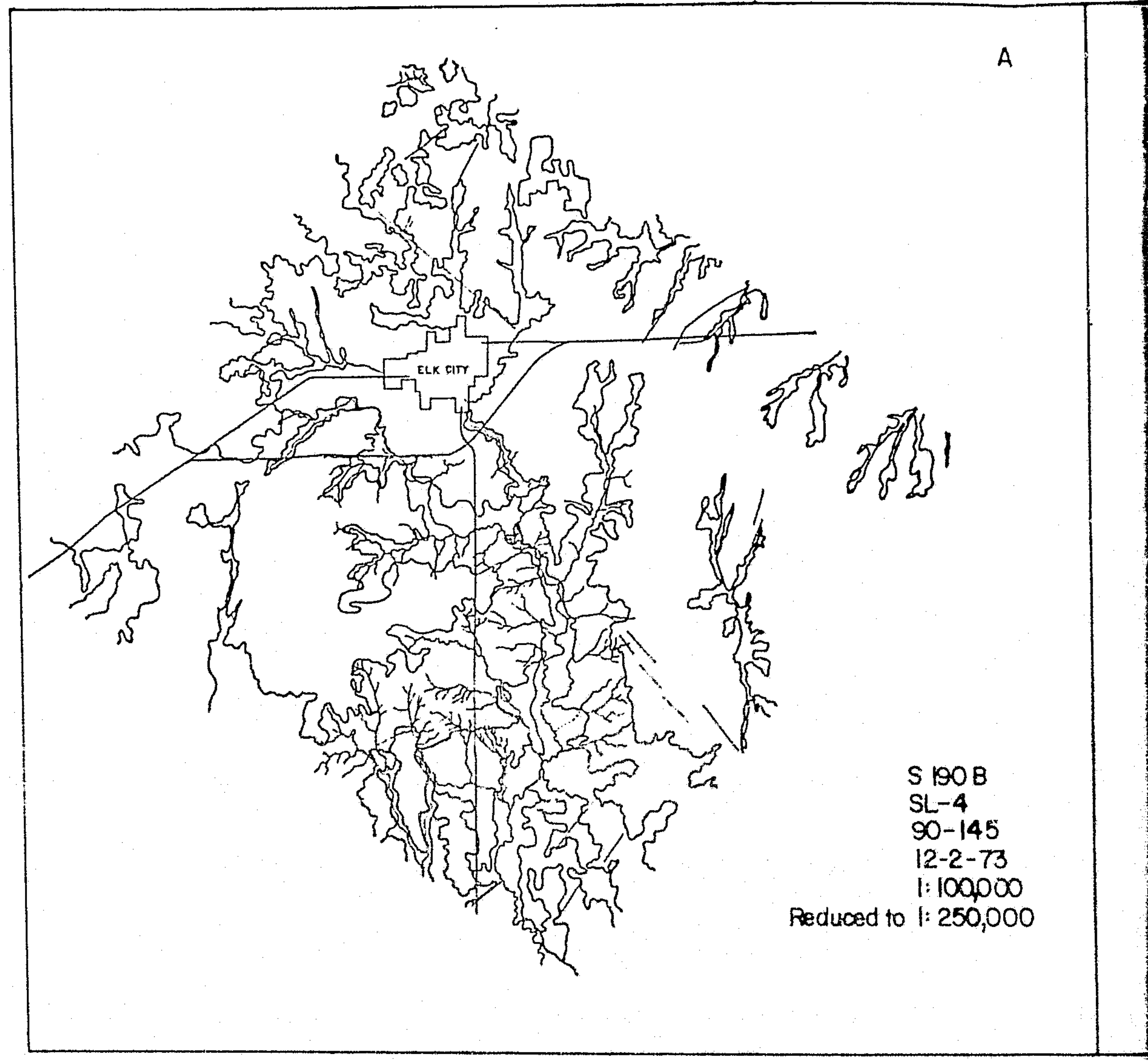
The large Elk City oil field is marked by an unimpressive anomaly. On S190A at 1:700,000 it was recognized as a circular tonal anomaly on one band and as a vaguely circular feature associated with deflected drainage on another band (figure 23). On S190B at 1:250,000 and 1:100,000 the Elk City field was noted only during detailed drainage analysis. The site is occupied by an anomalous stream bend whose tributaries drain the surface in a radial pattern. The outcrop pattern as seen from Skylab is not clearly indicative of the subsurface anticline.

Southeast Cheyenne:

The area in southern Roger Mills County near T.12 and 13N.-R.22 and 23W. (figure 24) has shown enough promise to warrant several wildcat operations. The anomaly consists of arcuate drainage in the Beaverdam Creek - Sandstone Creek basins and is a topographically low area partly embayed into the upland on the south, which seems to indicate structure at depth. The deepest hole went to 20,350 ft. All holes have been dry with the exception of non-commercial shows below 13,500 ft. in the deep hole. The area is outlined by residual gravity anomalies and has two airphoto anomalies. There are two faults postulated for this location. The azimuths of the linears are compatible with the general patterns of faulting in the area. However, drilling has not proved these faults nor defined any structural feature. A test is currently drilling just to the west below 7000 ft. and should help give a better picture of the remaining possibilities within the anomaly.

Summary

Skylab images provide several kinds of anomalies. Closed subcircular geomorphic anomalies show the highest correlation with features known to be associated with hydrocarbons. In areas of mature dissection there are many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S 190 B
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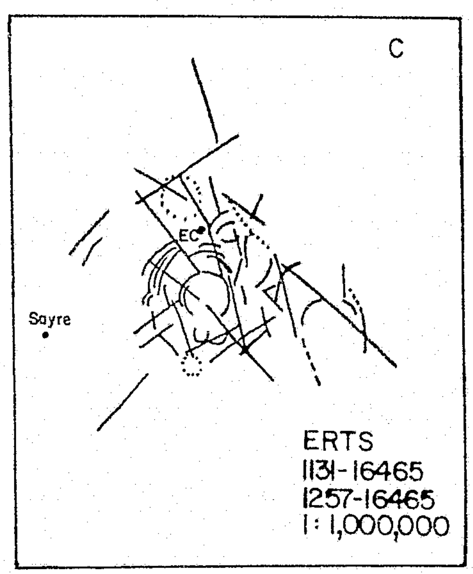
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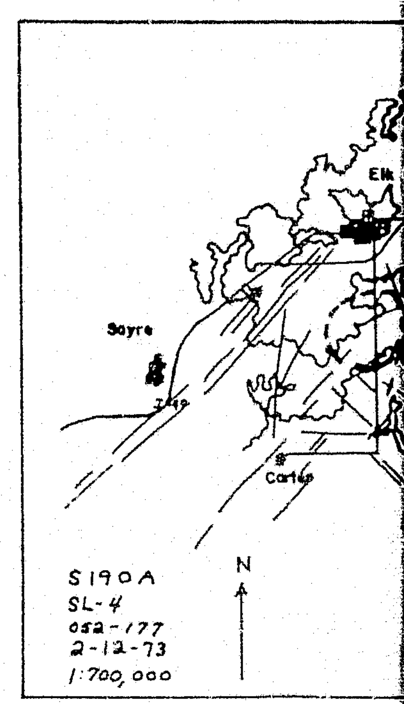
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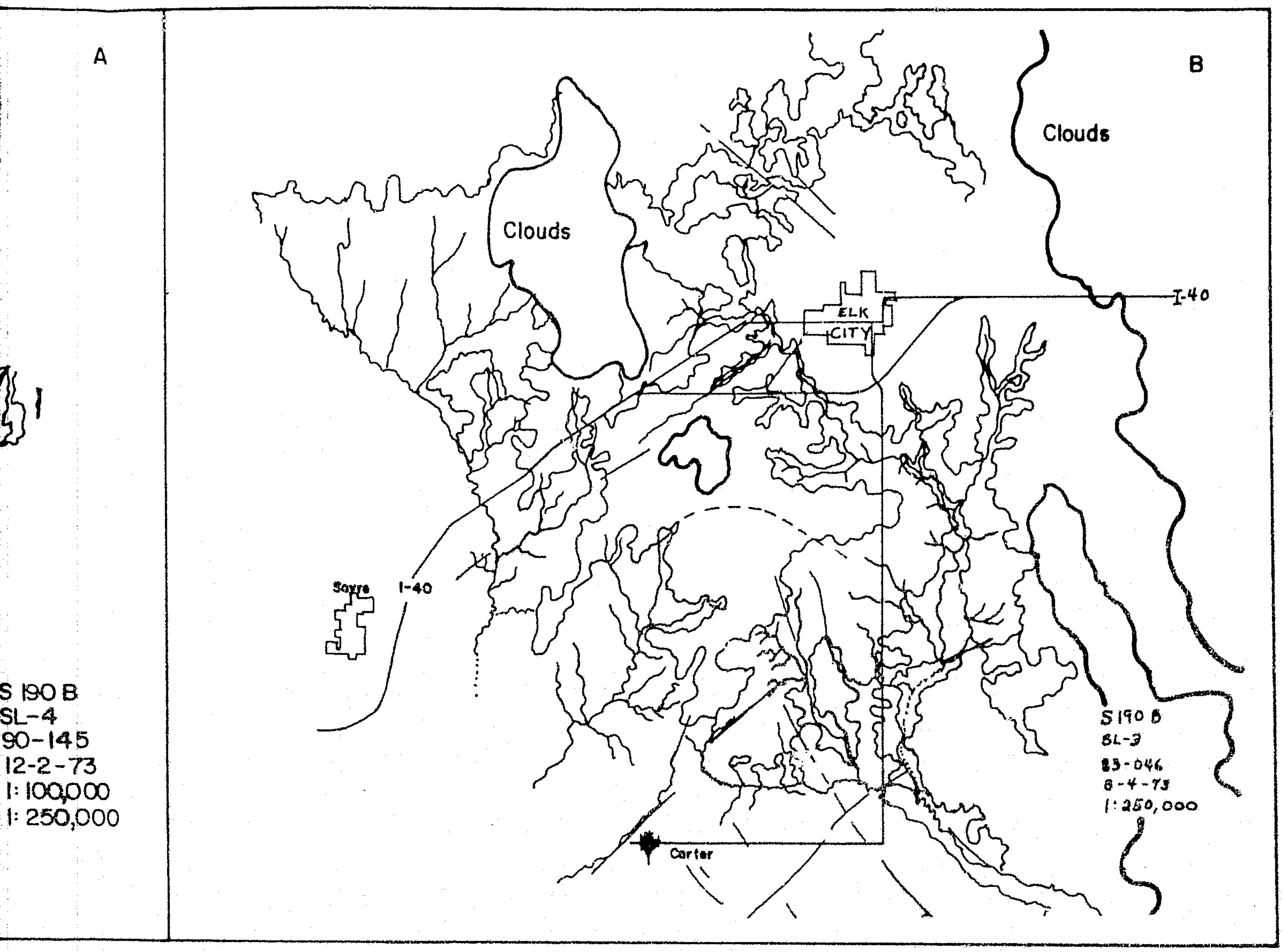

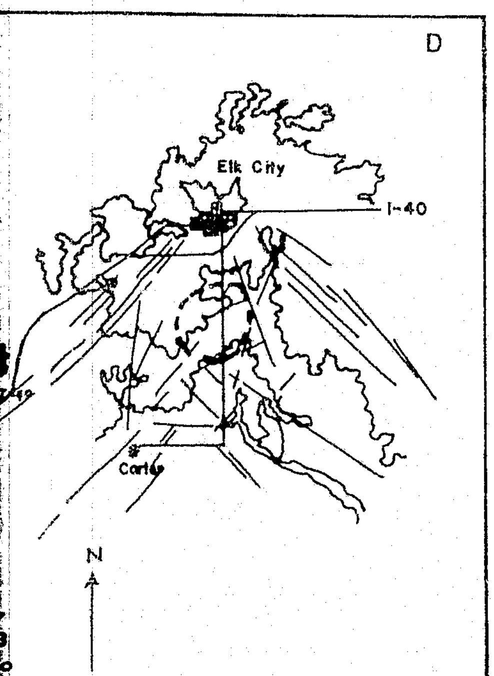

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Figure 23 .The Elk City anomaly that is prominent on Landsat (ERTS) images (C) is an indistinct, unimpressive anomaly appearing only on certain S190A bands and passes (D). The interpretation shown as (D) is from 241 mm (9 in.) color film. S190B color prints from August (A) and December (B) 1973 do not show an obvious anomaly although analysis of the interpretations gives some hint of an underlying structure. Interpretations (A) (B) and (D) demonstrate the effects of differing sensors, scales, atmospheric conditions, sun angles and seasons. (D) provides the most general lithologic interpretation. (A) is far superior to the others for drainage studies. Although (A) provides greatest apparent lithologic detail, the most accurate interpretation was done from (B).

spurious anomalies. Care must be taken to select true anomalies by drainage and fracture analysis. When compared to anomalies derived from Landsat images, Skylab anomalies are fewer. The high resolution of Skylab photos permits some Landsat anomalies to be eliminated. The geologic basis of others is made clear and confidence in the anomalies is increased. The multispectral-multisensor capability of Skylab enabled us to perform detailed studies on individual anomalies. Such analysis aids the selection of prospects. For example, the Turkey Creek and Leedey anomalies were found to be substantial and worthy of further investigation. Elk City would have been overlooked save for its character on Landsat. The Reydon anomalies are confusing and would be of lower priority for continued interest as part of an exploration program than either Leedey or Turkey Creek. The status of Southeast Cheyenne remains uncertain even after several tests have been drilled.

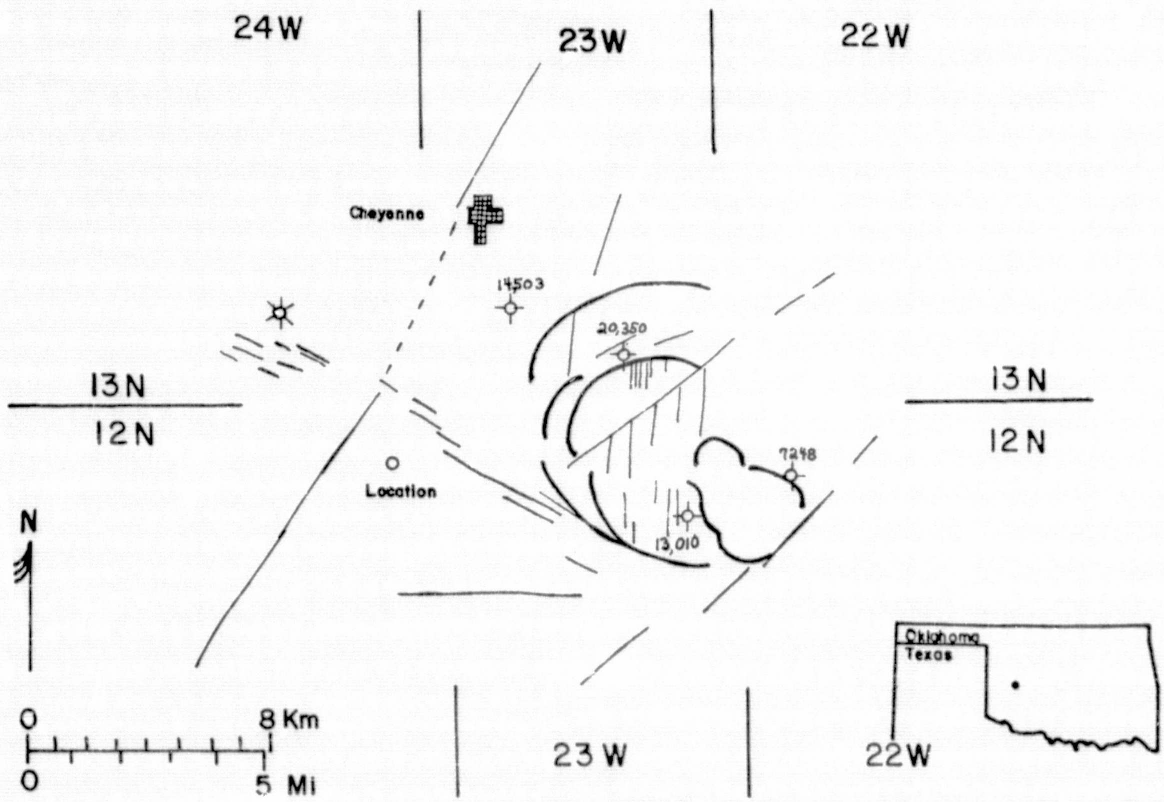

Figure 24 . The Southeast Cheyenne anomaly is an arcuate geomorphic type. It seems to be a promising anomaly. However, several tests have been drilled and all are dry. Only the 20,350 ft hole had a significant but non-commercial show.

CONTRIBUTIONS TO GEOLOGICAL MODEL OF THE ANADARKO BASIN

Virtually everyone who has used Skylab or Landsat data for geological exploration has commented on the value of synoptic coverage provided by these systems and the wealth of previously unreported linear features observed in the imagery. Both observations certainly apply to the Anadarko Basin (Collins et al., 1974).

The generally accepted model of the Anadarko Basin is that of a large west-northwest plunging syncline with much of the structural relief on the south flank provided by reverse faults down-to-the-north. In this model the north flank is visualized as gently downwarped with a few faults and minor folds being important from the detailed exploration standpoint, but affecting the overall structural picture very little (figure 1).

Skylab and Landsat imagery both indicate the presence of numerous long lineaments in the northern part of the basin. Field checking indicates that along many of these features there is evidence of fracturing in the form of small faults, deformed beds, steep dips, sandstone dikes, selenite veins, breccia, contorted gypsum beds, increased jointing, and persistent joint sets. Many of these features were previously known but unmapped. This is a natural consequence of exposures being widely separated, limited in extent, and rather poor. Also, thick Permian salt and gypsum beds are known to underly much of the basin and are believed to have been much more extensive in the past. Hence, it is widely believed that much of the disturbance seen at the surface is related to collapse as the result of solution of the evaporite rocks. These features appeared to be isolated, randomly distributed and unrelated to the overall structure of the basin and consequently were left unmapped.

Undoubtedly, many of these features are related to solution collapse (Jordan and Vosburg, 1963). However, comparing the lineaments seen in the space imagery to Jordan and Vosburg's maps (Collins, et. al., 1974) one is impressed with the fact that a significant amount of salt solution could be related to lineaments. Further, using the lineament maps constructed from the space imagery as a guide, we found during field checking that many of these supposedly unrelated structural disturbances lie along lineaments. Thus, the Skylab and Landsat imagery seem to bring some order out of what previously was thought to be chaos.

The next question was, what was the relationship of these

surface features to the rocks beneath the post-tectonic late Pennsylvanian-early Permian unconformity? Or do these surface features have any relationship to older features of interest to petroleum exploration? Upon comparing the lineament maps to the records of several regional seismic lines, we found substantial correspondence between lineaments and faults indicated by the seismic data. The correspondence is not one-to-one. However, the correlation seems to be stronger for longer lineaments than for shorter ones, which suggests one means of separating important lineaments from trivial features.

The coincidence of these inferred fracture zones with known structural features of the basin suggests that faulting may have played a major role in the development and present configuration of the north flank of the Anadarko Basin. This is not to say that folding and warping are not present or important, but rather to suggest that it may be useful to explore portions of the basin with the idea that the structural closures being sought (either fold or fault created) may be more closely related to faulting than to simple flexure. There is some evidence that specific features that are known as folds at the horizons where they are producing are, in reality, fault blocks at depth, and the folds are the result of drag on the bounding faults and sediment drape over the fault bounded features.

Recently, some workers have suggested that the Anadarko Basin is an incipient rift zone (in terms of plate tectonics) that never really fully developed. This model implies that there may be a significant amount of strike slip faulting, but no single fault would show any great amount of displacement. Further, normal faults should make up much of the structural framework of the basin. This type of tectonic environment can produce the types of features traditionally associated with vertical tectonics and more recently suggested to be associated with wrench fault tectonics (Lowell, 1969 and 1972). These features would include folds and associated reverse faults whose dips increase with increasing depth. This type of deformation seems to be present along the southern flank of the basin, but the axial trough and north flank of the basin seem to be controlled by normal faulting (figure 25).

Confirmation or disproof of this hypothesis and the development of a realistic integrated geologic model of the Anadarko Basin will require integration of the wealth of geological and geophysical data that presently exists in widely scattered depositories. Nonetheless, it is

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clear that examination of Skylab and Landsat imagery can contribute significantly to the understanding of regional structure and tectonics of interest to petroleum exploration.

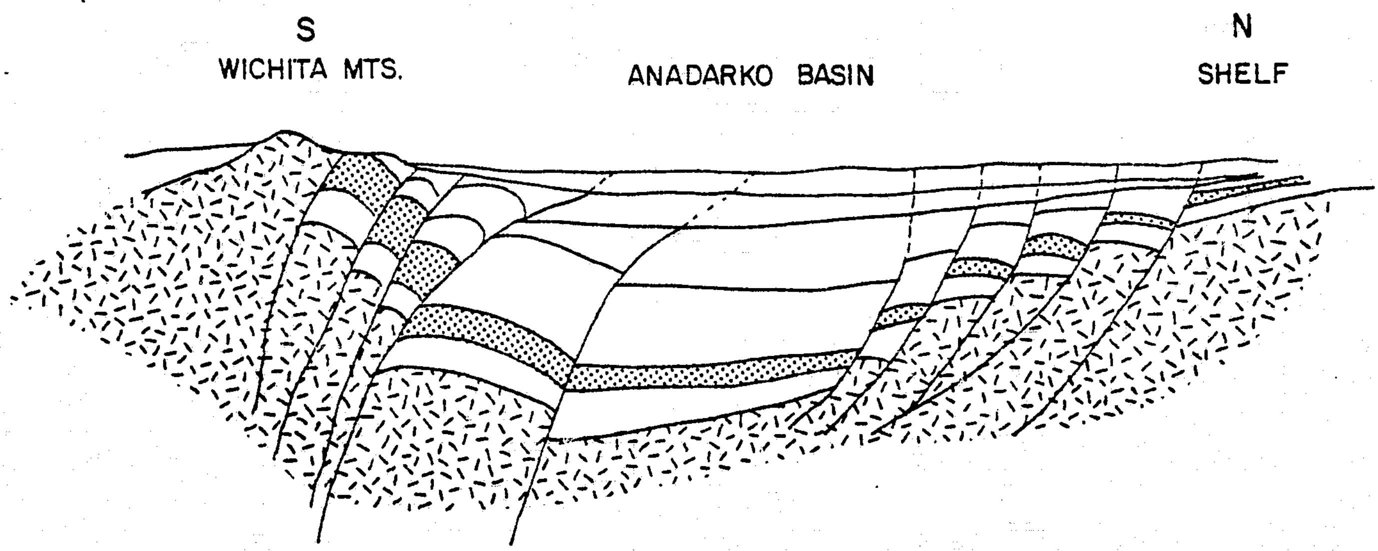


Figure 25 . Schematic cross section of the Anadarko Basin as hypothesized from satellite imagery.

V. SPACE IMAGERY IN AN EXPLORATION PROGRAM

SPACE IMAGERY IN AN EXPLORATION PROGRAM

Remotely sensed geologic data certainly do not provide a means of directly locating hydrocarbon deposits. Skylab and other data collecting platforms are a means of investigating surface features only. Such data extend our knowledge of geologic phenomena beyond visible features. The S192 scanner, with its capability of sensing thermal infrared wavelengths, extends exploration possibilities into night time hours. This new knowledge is integrated with other geologic information to derive a "picture" or hypothesis concerning subsurface geologic conditions. Satellite data become useful in this manner only when manipulated, studied and integrated by skilled, creative interpreters. Otherwise, the images and tapes remain curiosities.

Skylab imagery provides a new data base for petroleum exploration. Only the Landsat (ERTS) satellites before it have been widely used on a regular, formal basis in exploration. The nature and variety of Skylab data facilitate their incorporation into several aspects or stages of the exploration process. The orbital viewpoint of Skylab is a definite advantage for regional studies, providing large areas on single images. This enables users to see the "forest" instead of the "trees", perceiving interrelationships instead of details of geologic features. In addition, Skylab provides high resolution color photographs in some areas that previously had not been photographed.

Four General Methods of Using Skylab Data

Regional geologic reconnaissance can be performed quickly and efficiently and without the problems inherent in large photo mosaics. Satellite data are particularly useful in areas where little or no exploration has been undertaken or in areas that a company is entering for the first time. Even in well known areas, the unique perspective provided by space imagery may permit formulation of new hypotheses, alteration, extension or refinement of earlier studies or discovery of previously unknown geologic features. In other words, one fundamental use of Skylab data is the establishment of a data base upon which further exploration can be conducted. The structural setting of an area, rock types and their distribution, climate, vegetation, topography, access and availability of facilities such as roads, rails, towns, pipelines, water can all be determined to a satisfactory degree, particularly where S190B photos are available. Exploration can be focused on anomalies or more local, promising areas providing savings in time, manpower and other resources.

A second method employs the Skylab images in detailed analyses of existing prospects and of promising areas identified earlier from regional imagery studies. In the former use new insights often can be gained, particularly when there are gaps in existing data or when problematical interpretations need be clarified. For instance, in a case where the existence of a fault has been determined by subsurface methods but where information on a continuation or termination of the fault is lacking, surface clues can often be found to guide further drilling. In addition, when promising areas have been located on a regional imagery interpretation, additional information can be gained by several means. First, careful study alone, concentrated on a restricted area, will provide more detailed information on the site. Other information can be gleaned by manipulating the scale or format of an image. Application of enhancement techniques will speed up interpretation and perhaps supply some new information. Certainly, once a site has been selected for further consideration, usually on the basis of only one or two images, a multiband approach then can be taken to glean additional insights.

A third, and perhaps most important use of space-acquired data is the use of the data as an integral part of everyday exploration. As new ideas or information are generated the space data and other data are checked one against the other for evidence that might confirm, modify or deny the hypothesis. This process provides continuous feed back of ideas and information. We believe this process will provide the greatest long term benefit from space-acquired imagery.

Fourth, Skylab images provide a perfect base for study and analysis of all existing data on a prospect. The imagery is an excellent mapping base and display base for discussion, particularly of regional data.

Examples

Skylab in New Exploration Areas:

Many areas of recent exploration interest are either unmapped or have been mapped long ago only in a general way. The prime use of satellite data in an unmapped province is to provide a reconnaissance geologic map as the first step, the very basis of further exploration of the area. Frequently, such maps are the first and only information until further study is done.

Important structures and tectonic elements frequently can be (and have been) mapped that previously were unknown.

Refined interpretation is done next from the satellite data to fill in details and provide new insights into the structural and tectonic elements found in the reconnaissance interpretation. Study can concentrate on interesting structures, lithologic features and anomalies to determine if further studies are warranted.

If earlier reconnaissance mapping exists, Skylab images can have several uses. High resolution photos by the Earth Terrain Camera (S190B) can be used to add significant detail. Moreover, most reconnaissance maps can usually be altered to provide more definite ideas on the nature and location of lithologic contacts, geomorphic features, drainage patterns and continuations or terminations of structures.

The synoptic view from satellites permits studies of an exploration province to be extended easily into adjoining tectonic provinces. A given province is never entirely free of the effects of tectonism in nearby areas. An understanding of the relations of one province to another can have a significant effect on the geologic picture of the area and therefore on exploration strategy. The new satellite data also can be used to reinterpret older reconnaissance maps in terms of newer theories and hypotheses of tectonics, deformation and sedimentation.

Skylab in Explored Areas:

Skylab data can be integrated in several ways with other data on an explored petroleum province such as the Anadarko Basin. Anomalous features can give leads to promising locations within the basin. Individual linears can be studied and compared to other geological and geophysical data to determine what, if any, significance they have for exploration. Clues to local subsurface structures can be found when linears are studied statistically in light of hypotheses on fracture formation and fracture analysis. Studies by Podwysocki (1974a) and Podwysocki and Gold (1974b) are examples of linears analysis for subsurface structures. These methods are generally used on localized prospects.

Even in well known areas, the new information derived from Skylab can produce new hypotheses on regional geological aspects. For example, section IV of this report gives the beginnings of our own reevaluation of the Anadarko Basin. New insights into the tectonics of a basin may lead to recognition of new structures and structural trends and stratigraphic features having hydrocarbon potential. Newly recognized structural elements can then aid in exploration for stratigraphic traps once the effects of the structures

on sedimentation are clarified.

Uses of Skylab Advantageous in New or Old Exploration Areas:

In any exploration province, new or old, satellite data can play a significant role in exploration strategy. Manpower and monetary and physical resources are conserved by setting priorities on the basis of the satellite information. Once the areas of highest interest are delimited, exploration is concentrated there. In a well known area where other information is in hand, leasing may be the next step, followed by detailed seismic work. In a new exploration area, the next steps may include aeromagnetic and gravity surveys accompanied by field mapping. Reconnaissance seismic data might be gathered next.

Use of the Skylab data is an effective means of guiding the collection of geophysical data in new and old exploration provinces. In a new province, efforts would be limited to specific areas of highest priority. In old and new areas the location, spacing and direction of geophysical data lines can be determined at least partially from trends and features derived from remotely sensed data.

The next step involves integration of all data to solve some of the ambiguities in the satellite interpretations, geological studies and geophysical data. A number of choices can be made at this point. Leasing may be done, further geophysical or geologic work may be called for, the prospect might be dropped or the area may be surveyed for an actual drillsite.

In any case, time, money and manpower are all conserved. Savings are effected by limiting the area to be studied and by judiciously deploying men and equipment and guiding their activities by means of careful use of Skylab-derived data. Quality of geophysical data are enhanced by proper selection of sites and lines.

Summary

Skylab imagery is a new source of significant geologic information providing a basis for initial exploration efforts. It can serve as a lead tool in developing prospects by allowing rapid identification of anomalous or otherwise interesting areas. It forms an excellent basis for extending and extrapolating data acquired in specific areas and is an excellent base for plotting regional data from other sources. Skylab imagery provides new insights to prospects identified from other types of data and can rapidly resolve some of the ambiguities inherent

in seismic and subsurface methods of exploration. It can provide significant savings in time, money, and technical manpower when used in conjunction with conventional data sources to narrow options in exploration. Perhaps most important of all, Skylab data provide a new perspective for viewing and thinking about an exploration province.

VI. COSTS AND BENEFITS

PROGRAM COSTS AND BENEFITS

It is easy to calculate the cost of this study. The cost of obtaining similar or equivalent information by more customary exploration means is difficult to estimate principally because there is a variety of options and hence prices available for obtaining reconnaissance data. Indeed, the types of data obtained by the two approaches are not precisley comparable.

Difficulties in Cost Estimating:

An oil company can obtain regional geophysical and comparable geological data in any one of several ways. It can:

1. Pay for the survey itself and have the data on a proprietary basis - expensive.

2. Join a "group shoot" and pay for and obtain the data jointly with several other companies with a more limited period of exclusivity - less expensive.

3. Wait until after reconnaissance surveys are run and then obtain the data essentially second hand when it has been released by the group who paid for the survey - least expensive and least timely.

The second problem of estimating costs is that the types of information obtained from Skylab data and customary reconnaissance techniques basically are not comparable. The information obtained from interpretation of space-acquired imagery is new information, different in significant respects from information obtained from conventional sources. This is not to say that Skylab information is better or worse than conventional data, but that it complements, extends, refines, and integrates conventional data in new ways that can provide new insights and form the basis for revised interpretations. On the other hand, reconnaissance geologic field work and seismic and aeromagnetic surveys provide a great deal more detailed and quantitative data than is obtainable from space. One method of dealing with this problem is to attempt to estimate the costs of arriving at a particular common point in an exploration program with Skylab and without its data. The common point we have tentatively chosen for this comparison is the point at which one would begin detailed surface mapping and begin to plan detailed seismic surveys and geochemical surveys (if indicated).

A Cost Estimate:

A program guided by interpretation of Skylab imagery would have to include the cost of air photo interpretation, reconnaissance geology, and seismic work over anomalies identified in the Skylab imagery in order to be comparable to the conventional program. For instance, we found approximately 110 anomalies with an average diameter of 6 km and a total area of about 3,000 sq km. On the basis of airphoto interpretation and field work one might choose 50 of these on which to acquire seismic information. Acquisition of a cross pattern of seismic lines over these anomalies would require about 600 line km of seismic work. The cost of the Skylab data is assumed to be small and is included in the cost of the interpretation.

Using a customary approach to regional exploration probably would entail acquiring an airphoto interpretation and reconnaissance seismic coverage over the entire area. A reconnaissance seismic survey would require about 4,600 line km of shooting (covering the 80,000 sq km area on a 30 X 40 km grid). One probably would want to obtain a standard airphoto interpretation of the entire area. Anomalies located with regional seismic work and airphoto interpretations would be covered with a cross pattern of seismic lines. For purposes of comparison we assume that about the same number of anomalies would be examined in both programs. This would require an additional 600 line km of seismic survey.

Both the conventional and Skylab-assisted exploration programs probably would include reconnaissance aeromagnetic surveys and regional gravity surveys of the entire area. However, it is probable that the Skylab interpretation could reduce the amount of gravity data required. Both programs would include a review of available geologic information.

In the conventional survey the reconnaissance seismic, and airphoto interpretation probably would be acquired on a non-exclusive basis. In the Skylab program the air photo interpretation over the Skylab anomalies probably would be acquired on an exclusive basis so as not to reveal one's intentions. The area examined by photo interpretation would be about twice that covered by the anomalies so as to provide an interpretative context. In both surveys the seismic work over anomalies would almost certainly be acquired on an exclusive basis. Under this set of assumptions (probable mode) the conventional program would cost about 1.4 million dollars and the Skylab program would cost approximately 0.8 million dollars. The Skylab program

would represent approximately a 40% savings over the conventional program. If a company were entering a relatively explored area the savings would not be as great because considerable second-hand geophysical data would be available at a significant cost savings. On the contrary, if a company were beginning exploration in a totally new area the cost of a conventional program would be considerably higher because little second-hand or "group shoot" data would be available, and the benefit ratio for the Skylab program would be considerably higher. Expenses involved in a conventional exploration program and a Skylab-based program are summarized in table 10.

A. Conventional Program

	Non-Exclusive	Exclusive	Probable Mode of Acquisition
Reconnaissance Seismic Survey (4,600 Kilometers)	$420,000*	$5,520,000	$ 420,000
Air Photo Interpretation (80,000 Square Kilometers)	64,000*	200,000	64,000
Reconnaissance Surface Geology	200,000	200,000*	200,000
Seismic Survey Across Anomalies (600 Kilometers)	50,400	720,000*	720,000
TOTAL	$734,400	$6,640,000	$1,404,000

B. SKYLAB Program

	Non-Exclusive	Exclusive	Probable Mode of Acquisition
SKYLAB Interpretation Including Comparison to Air Photos	$ 24,000	$ 24,000*	$ 24,000
Seismic Survey Across Anomalies (600 Kilometers)	50,400	720,000*	720,000
Air Photo Interpretation of Anomalies (6,000 Square Kilometers)	4,800	15,000*	15,000
Reconnaissance Surface Geology Over Anomalies (6,000 Square Kilometers)	21,000	21,000*	21,000
TOTAL	$100,200	$ 780,000	$ 780,000

*Indicates probable mode of acquiring the data.

Table 10 Comparison of cost of a regional exploration program: A. Using conventional methods. B. Using SKYLAB data

Other Possibilities:

Table 10 represents only one of many possible permutations and combinations of types of data and ways in which the data in each program could be acquired. For instance, the kinds of data to be collected depend on the area to be studied and the experience of the exploration group conducting the study. It is unlikely that all of the anomalies found in either program would be covered by seismic lines. A company could very well choose to examine only part of a basin in detail based on preliminary seismic work conducted in either program or leasing conditions. Thus the prices of the two approaches may be nearly the same at one extreme. At the other extreme, the conventional approach would cost almost twice as much as the Skylab approach. The costs of both programs are most sensitive to the amount of seismic data acquired and to the basis on which it is acquired.

Another possibility, difficult to evaluate, is that much exploration conducted by companies is based to some degree on prospects brought in by other groups. In this mode of operation time is of the essence. If the Skylab data are on hand in a desirable form, their contribution to a decision can be considerable. If the data are not readily available there is, of course, no contribution. It is difficult to estimate the dollar contribution of Skylab to such an intangible as a decision to proceed or not proceed with a prospect.

The costs of individual elements of the program can also vary considerably. For example, field geology in all but the most straightforward, well-developed areas (good roads) would certainly cost considerably more without Skylab interpretations. The same is true of seismic surveys. Because the conventional program includes a larger proportion of both these elements, it is probable that under most circumstances the cost ratios will be even more in favor of the Skylab approach than is indicated here.

Time Savings:

None of these comparisons takes account of the time saved using the Skylab approach either in terms of the technical and management time saved or in terms of the competitive edge gained through more rapid evaluation of the exploration province and accelerated decision making. Intuitively we feel these savings could be substantial but find no sound set of assumptions or methodology upon which to base an analysis.

Skylab Compared to Landsat:

It is difficult to compare costs and benefits of Landsat and Skylab data. The higher resolution and stereo coverage of Skylab photos make Skylab better for most types of interpretations of interest in petroleum exploration. The nature of the Skylab data make it easier to relate to than Landsat data for most photointerpreters. We found that where good Skylab coverage exists the level of detail obtained by interpretation of a single coverage is somewhat better than that obtained from interpretation of four or more cloud free coverages of Landsat data even when obtained during two different seasons. On the other hand, the repeated coverage provided by Landsat does provide a significant advantage in terms of extractable data (by virtue of different illumination angles and climatic conditions) and in a higher probability that a particular area is covered by usable imagery. The Landsat swath widths and orbits provide complete coverage of the earth; whereas, Skylab's orbits and swaths leave major areas of the earth uncovered. Coverage is incomplete even in the U. S.

If good Skylab data are available for a particular area, we believe that, if one were forced to choose, one should use Skylab rather than Landsat data and that there is a cost advantage over Landsat data. However, we believe that Skylab and Landsat data complement each other rather than substitute for one another and both should be used whenever this is feasible.

VII. APPENDICES

APPENDIX A.

ABBREVIATIONS and SYMBOLS

BOPD	Barrels of Oil Per Day
CAOF	Calculated Absolute Open Flow (potential)
EREP	Earth Resources Experiment Package
EVA	Extra-Vehicular Activity
ERTS	Earth Resources Technology Satellite (renamed Landsat)
IP	Initial Production
IR	Infrared
JSC	Lyndon B. Johnson Space Center, Houston, Texas
Landsat	A series of earth resources survey satellites. Formerly named ERTS.
MCFGPD	Thousand Cubic Feet of Gas Per Day
MSS	Multispectral Scanner aboard Landsat (ERTS)
NASA	National Aeronautics and Space Administration
OPEC	Organization of Petroleum Exporting Countries
SDO	Scientific Data Output (digital tape channel)
S190A	Skylab multispectral camera system
S190B	Skylab high resolution (Earth Terrain) Camera
S192	Skylab multispectral scanner
USGS	U. S. Geological Survey

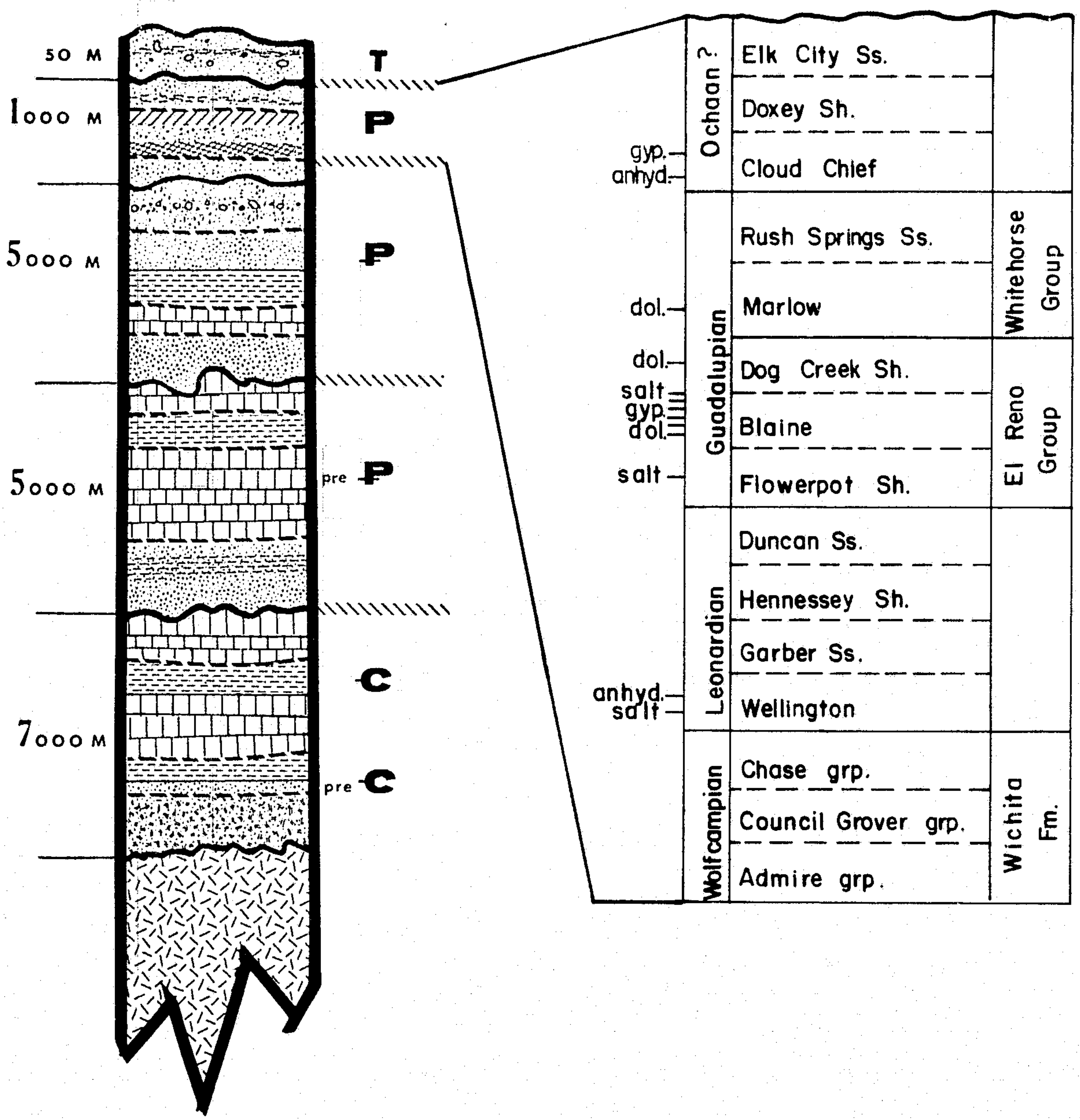
- oil well
- gas well
- proposed well location
- dry & abandoned hole

Permian Stratigraphy

Pec	Elk City
Pdy	Doxey
Pcc	Cloud Chief
Prs	Rush Springs
Pm	Marlow
Pdc	Dog Creek
Pb	Blaine
Pf	Flowerpot
Pd	Duncan
Ph	Hennessey
Pg	Garber
Pw	Wellington

APPENDIX B.

GENERALIZED STRATIGRAPHY, ANADARKO BASIN



Simplified stratigraphic column for the Anadarko Basin, showing the late Precambrian and Cambrian (pre-Ꞓ, Ꞓ) sedimentary and igneous rocks, pre-Pennsylvanian (pre-₱) miogeosynclinal rocks, Pennsylvanian (₱) clastic sedimentary rocks deposited during orogenic downwarp of the basin and uplift of the Wichita-Amarillo Mountain system, and Permian (P) late stage basin fill composed of red beds and evaporites. A thin cover of Tertiary rocks (T) occurs in the western part of the basin.

APPENDIX C.

IMAGERY and DIGITAL TAPES
SUPPLIED by NASA

SKYLAB Imagery

Sensor	Mission	Date	Track	Pass	Roll	Frame	Format 70 mm	5"	9"	Trans.	Other
S190A	2	6 -11-73	48	8	13-18	025-033	X		X	X	
S190A	3	8 - 4-73	48	13	19-24	111-113	X		X	X	
S190A	4	12- 2-73	48	56	51,52	175-182	X		X	X	
					51(IR)	175-182	X		X	X	
					52(Red)	175-182	X		X	X	
					52(Green)	175-182	X		X	X	
S190A	4	1 -11-74	1	81	61-66	280-282	X		X	X	(63,64 9"only)
S190A	4	1 -30-74	48	96	A1, A2	192-196	X		X	X	
					A5, A6	192-196	X		X	X	
S190B	3	8 - 4-73	48	13	83	043-046		X	X	X	(18" tr.,prt.)
S190B	4	12- 2-73	48	56	90	141-152		X	X	X	
S190B	4	1 -11-74	58	81	92	040-045		X	X	X	
S190B	4	1 -30-74	48	96	94	172-175		X	X	X	
S192	2	6 -11-73	48	8		GMT 1518:05-1518:14			5" trans.		
S192	4	12- 2-73	48	56		GMT 1644:46-1645:44			5" trans.		
S192	4	1 -11-74	58	81		GMT 1734:04-1734:46			5" trans.		
S192	4	1 -27-74	2	92		GMT 1225:36-1228:20			5" trans.		

SKYLAB Digital Tapes

Sensor	JSC Accession No.	Channels
S192	32-02186+'87	
S192	32-12282+'83	
S192	32-12473+'74	1,3,5,7,9,11,13,17-22
S192	34-12421 thru 12430	1-8,11,12,15,16,20-22
S192	34-12598 thru 12608	All
S193	32-02677 thru 02679	NA
S193	33-12236 thru 12239	NA
S193	33-22851+'52	NA
S193	34-934112	NA

NASA Aircraft Coverage

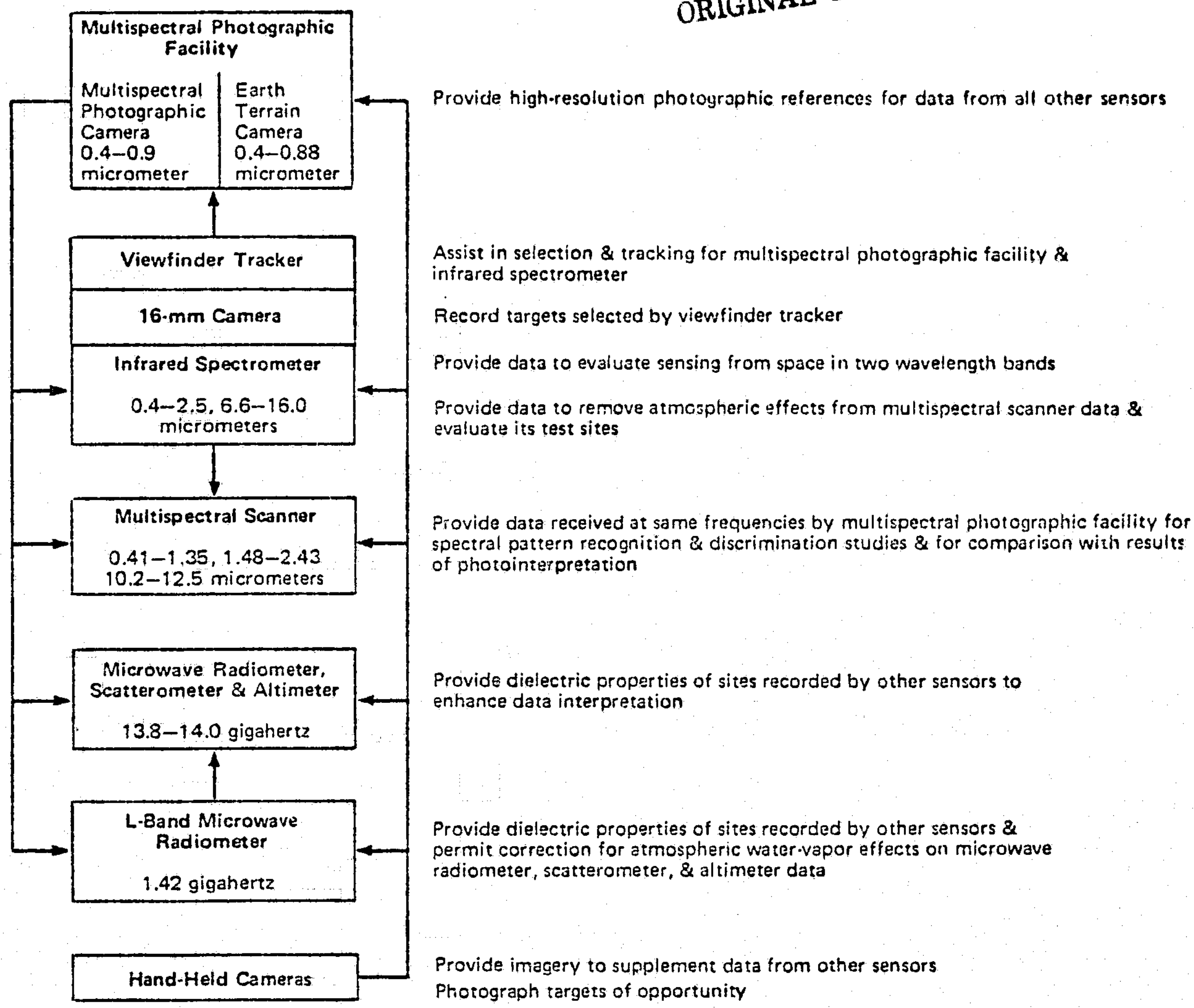
Sensor	Film	Filter	Frames	Mission
APQ/97	NA	NA	NA	83W
RS-14	NA	NA	NA	105
RC-8-1	SO-397	?	5216-5391	105
KA-62D	SO-246	89b	7452-7550	105
RC-8	2448	?	6615-6751	106
RC-8	SO-117	?	6955-7091	106
Hasselblad	3400	47,2e	23-116	106
Hasselblad	SO-368	?	23-118	106
RC-8	SO-397	2.2AV,2A	003-131	236
RC-8	2443	AV, 510nm	003-131	236
Zeiss	2443	515 nm	003-249	236
Hasselblad	2402	25	002-070	236
"	2402	57	" "	236
"	2424	89B	" "	236
"	2443	12,CC,30B	" "	236
"	2424	87	" "	236

Landsat (ERTS) Imagery

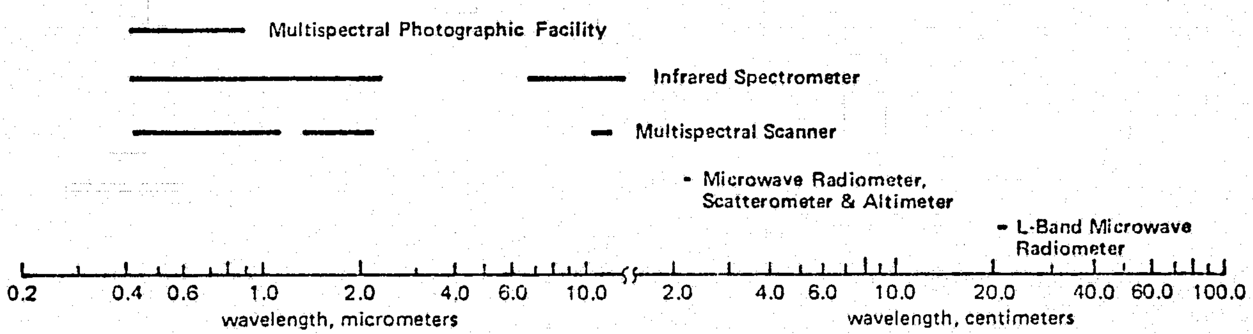
Frame	Format	Bands
1347-16462	9" B/W,Color	MSS 4,5,6,7
1384-16514	" " "	"
1401-16453	" " "	"
1508-16383	" " "	"

APPENDIX D.

SKYLAB SENSORS *



a. Functional Interrelationships



b. Spectral Interrelationships

Earth Resources Experiment Package Sensor Interrelationships

* from: Skylab Data Catalog JSC-09016

S190A Multispectral Cameras

Multispectral Camera Station Characteristics and Film Rolls Used

Sta	Filter	Filter Bandpass, micrometer	Film Type*	Estimated Ground Resolution††, feet (meters)	Mission & Roll No.		
					SL-2†	SL-3	SL-4
1	CC	0.7 – 0.8	EK 2424 (B&W infrared)	240 – 260 (73 – 79)	01 ,07,13	19,25,31, 37,43	49 ,55,61, 67,73,A1,1B
2	DD	0.8 – 0.9	EK 2424 (B&W infrared)	240 – 260 (73 – 79)	02,08,14	20,26,32, 38,44	50 ,56,62, 68,74,A2,2B
3	EE	0.5 – 0.88	EK 2443 (color infrared)	240 – 260 (73 – 79)	03,09,15	21,27,33, 39,45	51 ,57,63, 69,75,A3,3B
4	FF	0.4 – 0.7	SO-356 (hi-resolution color)	130 – 150 (40 – 46)	04,10,16	22,28,34, 40,46	52 ,58,64,70 76,A4,4B
5	BB	0.6 – 0.7	SO-022 (PANATOMIC-X B&W)	100 – 125 (30 – 38)	05,11,17	23,29,35, 41,47	53 ,59,65, 71,77,A5,5B
6	AA	0.5 – 0.6	SO-022 (PANATOMIC-X B&W)	130 – 150 (40 – 46)	06,12,18	24,30,36, 42,48	54 ,60,66, 72,78,A6,6B

* Eastman Kodak Company
† SL-1 was the launch of Skylab without crew.
†† At low contrast

Multispectral Camera Data Products

Scale*	Image Size, inch (cm)	Enlargement	Products: Black and White Transparency	Print	Color Transparency	Print
1:2,850,000	2.25 x 2.25 (5.72 x 5.72)	1.00X	Positive Negative	None	Positive†	None
1:1,000,000	6.41 x 6.41 (16.29 x 16.29)	2.85X	Positive Negative	Positive	Positive	Positive
1: 500,000	12.83 x 12.83 (32.50 x 32.50)	5.70X	Positive	Positive	None	Positive
1: 250,000	25.65 x 25.65 (65.15 x 65.15)	11.40X	Positive	Positive	None	Positive

* Scales are nominal, exact scale as printed will be supplied with the photos.

S190B High Resolution Camera

Earth Terrain Camera Film Characteristics and Rolls Used

Film Type*	Wratten Filter	Filter Bandpass, micrometer	Estimated Ground Resolution††, feet (meters)	Mission & Roll No.		
				SL-2	SL-3	SL-4
SO-242 (hi-resolution color)	none	0.4 – 0.7	70 (21)	81	83,84, 86,88	90,91, 92,94
EK 3414 (hi-definition B&W)	12†	0.5 – 0.7	55 (17)	82	85	89
EK 3443 (SL-2 & SL-3) (infrared color)	12	0.5 – 0.88	100 (30)	–	87	–
SO-131 (SL-4) (hi-resolution infrared color)	12	0.5 – 0.88	75 (23)	–	–	93

* Eastman Kodak Company
† "Minus blue" filter
†† at low contrast

Earth Terrain Camera Data Products

Scale*	Image Size, inch (cm)	Enlargement	Products: Black and White Transparency	Print	Color Transparency	Print
1:950,000	4.50 x 4.50 (11.43 x 11.43)	1.0X	Positive Negative	None	Positive†	Positive
1:500,000	8.55 x 8.55 (21.72 x 21.72)	1.9X	None	Positive	None	Positive
1:250,000	17.10 x 17.10 (43.43 x 43.43)	3.8X	None	Positive	None	Positive
1:125,000	34.20 x 34.20 (86.87 x 86.87)	7.6X	None	Positive	None	Positive

* Scales are nominal, exact scale as printed will be supplied with the photos.

192 Multispectral Scanner

Band No.	Wavelength, micrometers
1	0.41 – 0.45
2	0.44 – 0.52
3	0.49 – 0.56
4	0.53 – 0.61
5	0.59 – 0.67
6	0.64 – 0.76
7	0.75 – 0.90
8	0.90 – 1.08
9	1.00 – 1.24
10	1.10 – 1.35
11	1.48 – 1.85
12	2.00 – 2.43
13	10.20 – 12.50

The 0.182-milliradian field of view of each detector provided an instantaneous square ground coverage of 260 feet (79 meters), swept in a conical scan as shown in Figure 14. Although the scan assembly rotated a full 360 degrees, only the forward 110 degrees were used to obtain data. The corresponding sweep angle viewed from the sensor was 10.4 degrees, which provided a ground swath width of 40 nautical miles (74 kilometers).

Data from the multispectral scanner consist of computer-compatible tapes of raw or calibrated data with ancillary information such as tape format descriptions, calibration data, data-acquisition characteristics like time, spacecraft attitude, field of view, etc.

Selected data are processed to produce 5-inch (12.7-centimeter) film images from radiometrically corrected data. This imagery is in the form of black-and-white screening film for selected bands, color composites from up to three bands, or false color based on amplitude ranges from a single band. The latter is the equivalent of a density-sliced photographic image.

S193 Microwave Radiometer/Scatterometer

From radiometer measurements, the brightness temperature of the earth's surface within the field of view (1.6-degree half power) was determined as a function of incidence angle from surface normal to 48 degrees in the frequency range from 13.8 to 14 gigahertz. The mean value of the earth's thermal noise signal was determined by sufficiently long observations. The measured energy, converted to brightness temperature, was compared to the mean noise energy from two known internal temperature sources to yield an accurate proportional measurement of the earth's microwave emission within the instrument's field of view. Calibration was provided by comparing the measurement with two internal noise temperature sources.

The scatterometer measured the backscattering of radiation from the earth at 13.9 gigahertz as a function of incidence angles from 0 (vertical) to 48 degrees. The calculated scattering coefficient was related to the roughness and dielectric properties of the surface viewed. A number of measurements of the scattered return signal (which looks like thermal noise) and receiver noise were taken and integrated to obtain an accurate measurement of average return power from which the backscattering coefficient was calculated. By operating the radiometer and scatterometer concurrently, collections of paired values of the backscattering coefficient and apparent blackbody temperature for each surface measurement permitted separation of emissivity effects from reflectivity effects.

Data from the microwave radiometer and scatterometer consist of computer-compatible tapes of raw and processed data, including radiometer antenna temperature and scatterometer backscattering coefficients correlated with Greenwich Mean Time. Computer-compatible tapes of altimeter raw and processed data include a time history of automatic gain-control power, range measurements, and return-pulse shape information correlated with Greenwich Mean Time. Ancillary information includes tape format description, sensor data-acquisition characteristics like center of sensor field of view, and spacecraft attitude and velocity.

APPENDIX E.

SKYLAB TECHNICAL INFORMATION

SKYLAB PROGRAM Earth Resources Experiment Package:

Sensor Performance Evaluation (1975)

Final Report MSC-05546
NASA, Johnson Space Center, Houston, Texas
Volume I (S190A)
III (S192)
IV (S193 R/S)
VII (S190B)

SKYLAB PROGRAM Earth Resources Experiment Package:

Sensor Performance Report (1974)
Final Report MSC-05528
NASA, Johnson Space Center, Houston, Texas
Volume I (S190A)
III (S192)
IV (S193 R/S)
VII (S190B)

SKYLAB Earth Resources Data Catalogue (1975)

Publication JSC 09016
NASA, Johnson Space Center, Houston, Texas

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_____ Petzel, G. J., and Everett, J. R. (1975b) Evaluation of the suitability of Skylab data for the purpose of petroleum exploration: Quarterly Report, March 1975, NASA Contract 9-13297, Eason Oil Co., Oklahoma City, 20 p.

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